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Habitat Conditions in the Transitional Faunal Zone in Central Nepal

(A report on the German Zoological Expedition to Central Nepal 1973)

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Abstract

Data of vegetation and climate are collected and compiled for the area studied which includes the Annapurna south slope and the Kali Gandaki valley up to Jomosom. All habitats visited are described from the ecological point of view. There is a close correlation between the conditions studied and the distribution of animals of Palaearctic and Oriental origin. The transitional zone between the faunal regions mentioned is very narrow and can be determined by meteorological factors and by the vegetation which includes many indicator plant species. Special investigations have been done on the factors influencing ground living animals. The importance of the environmental factors on the zoogeographic situation of the area is discussed.

1. Introduction

This paper was prepared in order to collect and demonstrate basic ecological data concerning the climate and vegetation of an area which shows very varying conditions within short distances and, in this way, may be an unique model for the ecological interrelationships. The area is the southern slope of the Annapurna range and the upper Kali Gandaki valley which crosses the main Himalaya range between the 8000 meter mountains Dhaulagiri and Annapurna in Central Nepal. Here, in connection with the conditions mentioned above, we find a virtual border between two different types of climate and vegetation and the limits of the Palaearctic and Oriental zoogeographic regions. The system varies in horizontal as well as in vertical directions forming a most fascinating zonation.

The studies, we did there, were to find relations between distribution and ecological factors, microevolution by isolating ecological factors, ecology, biodynamics and evolution of selected lepidopterous insects and ground living vertebrates. The results of the special studies will be dealt with elsewhere; here we want to publish the basis data observed by ourselves and compiled from different sources. In this way we hope to give information to all those doing studies in Nepal and to increase the knowledge of this most charming and interesting country.

2. Acknowledgements

We wish to express our hearty thanks to Deutsche Forschungsgemeinschaft which sponsored the studies by a grant, to the management of Thyssen House in Kathmandu, the late Prof. W. Hellmich and Mr. G. B. Kalikote, where we were living as guests for a time and could finish the preparations for the field work. We are most grateful for the help recieved by the authorities of His Majesty's Government of Nepal, The Foreign Office, The Ministry of Education and The Ministry of Forestry. We are indepted to the authorities of the Tribhuwan University, especially the Head of the Zoological Department, who sponsored our intensions and who delegated Mr. K. B. Kharki, a graduated zoologist, as liaison officer, who became a most helpful and friendly member of the party. We have to give our thanks to the local authorities of Gandaki and Dhaulagiri Zones, from whom we received much assistance. Many thanks also to our collaborators Mr. D. Fuchs and Mr. E. Lehmann, who took part in the field work, and to Mrs. and Mr. Krammig, who joined the party for some time doing photographic work. For the help of our Sherpateam which accompanied us during the trip we give many thanks, nice fellows as they were. We are grateful for the supply of special equipment, films, food and medicaments, by Agfa-Gaevert, Batscheider, Hartmann, Merck, Nestle-Maggi and Pfanni companies.

3. Vegetation

Vegetation types in the area visited have been described by several authors: Kihara (1955), Lobbichler (1961), Schweinfurt (1957) and finally by Dobremez and Jest (1971), who prepared a map showing the area of Annapurna and the Kali Gandaki valley. This map was basic information for our studies; also the vegetation map prepared by ourselves (fig. 1) which brings some corrections and additions elaborated during our field work.

The vegetation types show very clearly the great diversity of ecological conditions which occur at Annapurna and along the Kali Gandaki river, where the changes from one type to the other takes place within very short distances. In this way the ecological information is quite unique; there seems to be scarcely any other place in the world which can show comparable data. We also obtained information on the factors which determine the distribution of the Palaearctic and Oriental species in the horizontal as well as in the vertical direction.

It has sometimes been criticized that many papers on Nepalese biological topics repeat the description of vegetation types and zones, but we think there is nothing better to explain the ecological conditions than this. In a country like Nepal, where vegetation is still rather original, even when large areas are already badly influenced by man, the predominating plants are like indicators. Any biologist with some knowledge of plant species can, by careful observation, find out a lot of information concerning the local climatic conditions.

3.1 The area from Pokhara to Ghandrung

The area round Pokhara, the way to Naudara and even to Lumle and Birethanti is highly cultivated with small remainders of forest on steep slopes only. Usually up to 1000 m there is a zone of Sal, *Shorea robusta,* which is followed by *Schima-Castanopsis-Engelhardtia* higher up. The occurance of *Pandanus furcatus* near Birethanti, which indicates high humidity and a subtropical semi-evergreen forest (sensu Stainton), is remarkable. This type of forest is widespread in East Nepal; in

Central Nepal it is limited to wet and steep slopes of some river valleys. The ground of these valleys is covered with a subtropical river forest where *Alnus nepalensis* predominates. We find this type at Modi Khola up to Kyumnu Khola below camp 1 and at Kali Gandaki up to the gorge. Below Ghandrung at 2000 m we meet the damp forest of *Quercus lammellosa,* which encloses many other species and lots of epiphytic plants. Here is the limit of clouds which for many months during summer time give a continuous fog cover.

(Seiten 4 und 5)

Fig. 1: Distribution of vegetation types in the research area basing on the map of Dobremez and Jest, with additions and corrections.

Symbols for vegetation:

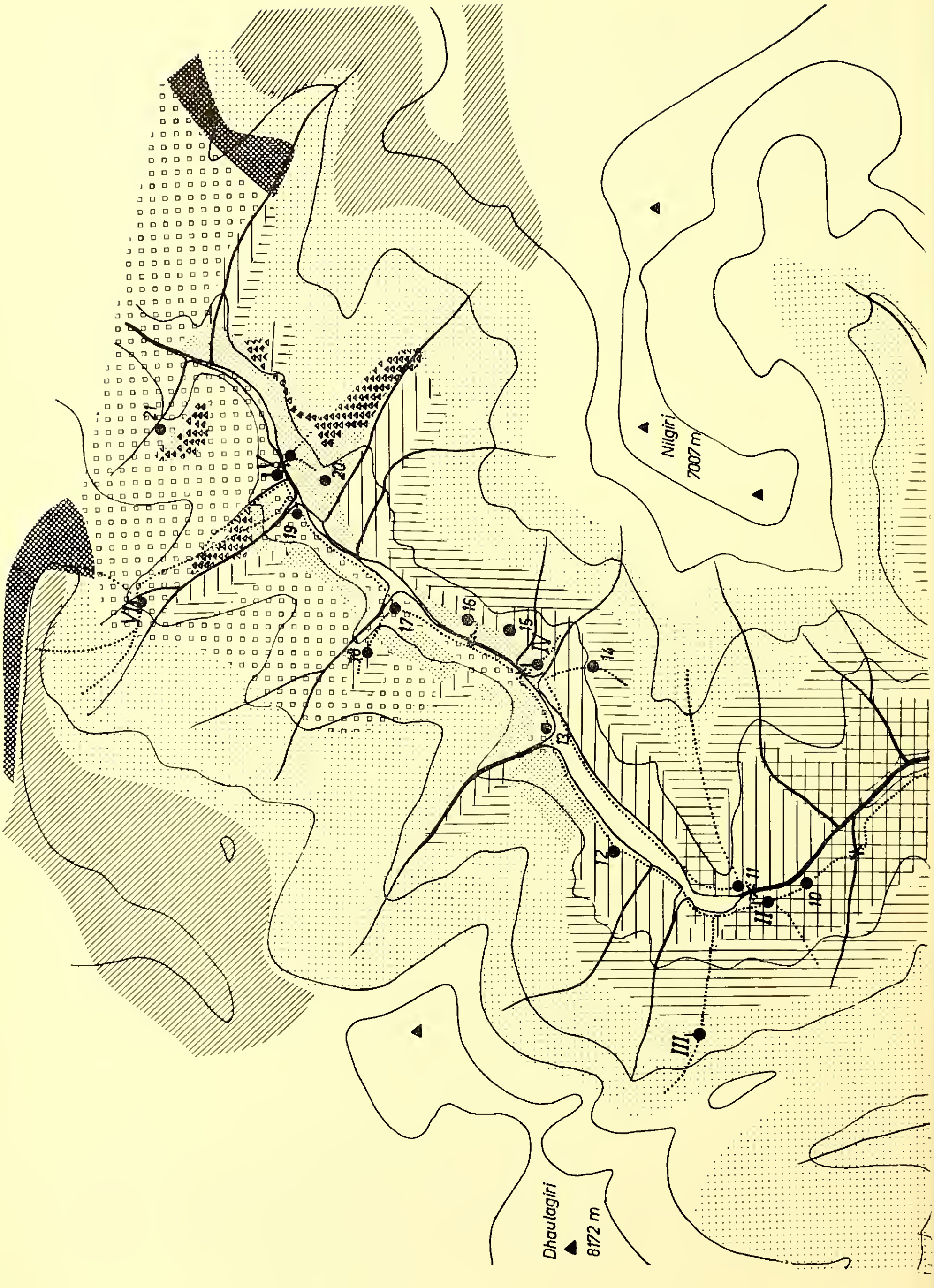
1 *Schima-Castanopsis-Engelhardtia* including *Alnus nepalensis*
2 *Pinus roxburghii*
3 *Quercus* forest of all types, zone of largest humidity
4 *Abies-Betula-Rhododendron* forest locally with *Tsuga*
5 Semihumid *Pinus excelsa* forest, with broadleaved trees
6 Semiarid *Pinus excelsa* forest
7 left, *Cupressus torulosa* predominating
7 right, *Juniperus indica* predominating
8 moist south himalayan alpine meadows
9 high alpine scattered plants
10 xerophile alpine steppe
11 steppes of *Caragana-Artemisia-Lonicera* (no divisions made here)

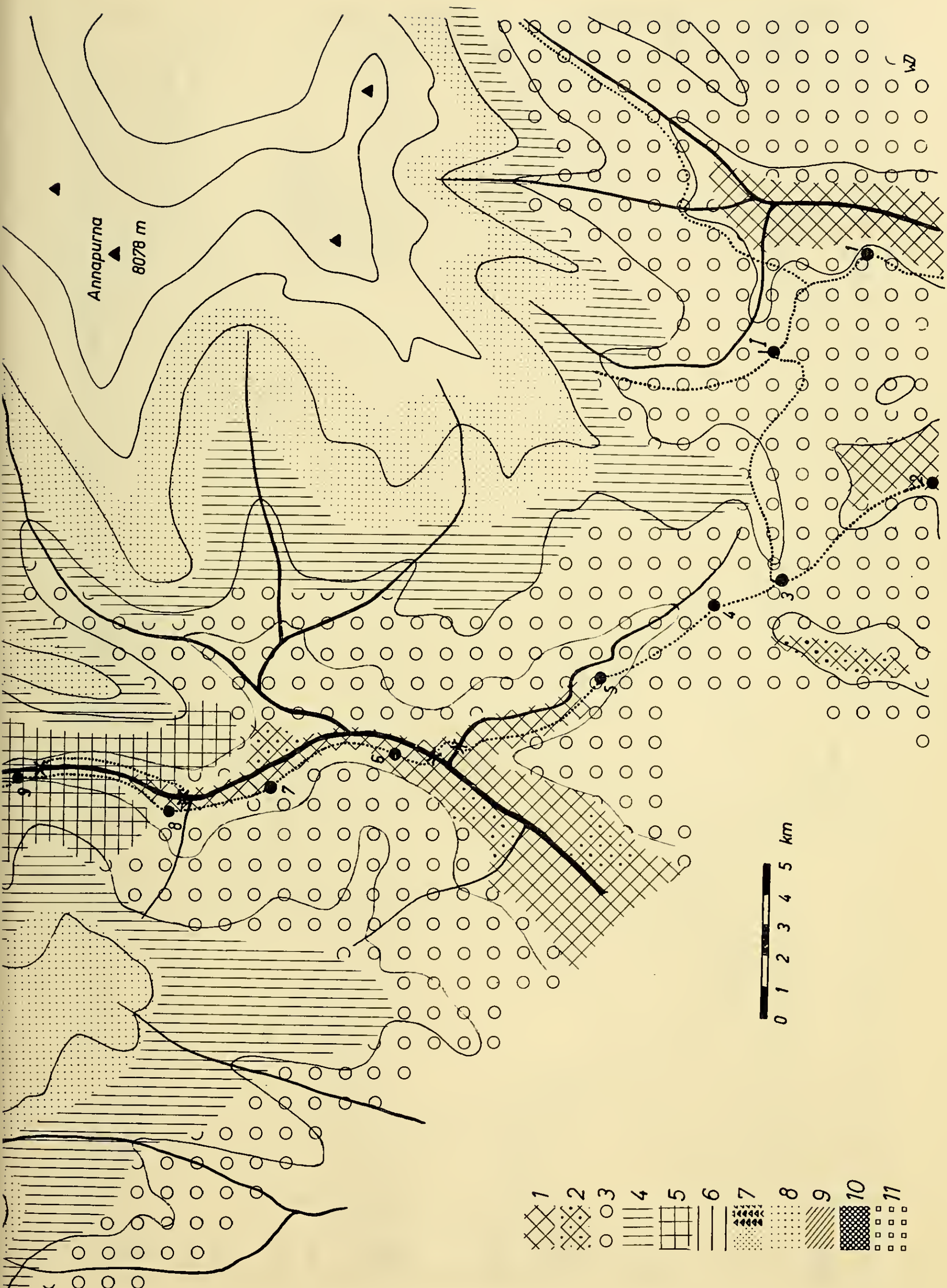
Figures:

1 Gandrung, 2 Ulleri, 3 Gorepani, 4 Chitre, 5 Sikha, 6 Tatopani, 7 Dana, 8 Kabre, 9 Ghasa, 10 Lethe, 11 Dhumpu, 12 Larjung, 13 Tukche, 14 Taksang, 15 Chimi, 16 Chhairo, 17 Marpha, 18 Old Marpha-Jhong, 19 Syang, 20 Thini, 21 Sangda.
Roman figures indicate camping sites
I Kyumnu Khola, II Kalopani, III Dhaulagiri south-east slope, IV Choklopani, V Jomosom, VI Syang Khola valley.
Distances in km, altitude in meter, contour intervals 1000 m.

(Seiten 6 und 7)

Fig. 2: Cross section through Kali Gandaki valley. Upper part, east side with Annapurna, lower part, west side with Dhaulagiri. East side with precipitation diagram (interrupted line) and rainfall scale in mm to the right. A cloud indicates the zone of fog and high amount of rainfall. For all other symbols see fig. 1. Triangles indicate important localities.


Nilgiri
7007 m
Dhaulagiri
8172 m


Annapurna
8078 m
0 1 2 3 4 5 km
WD
1
2
3
4
5
6
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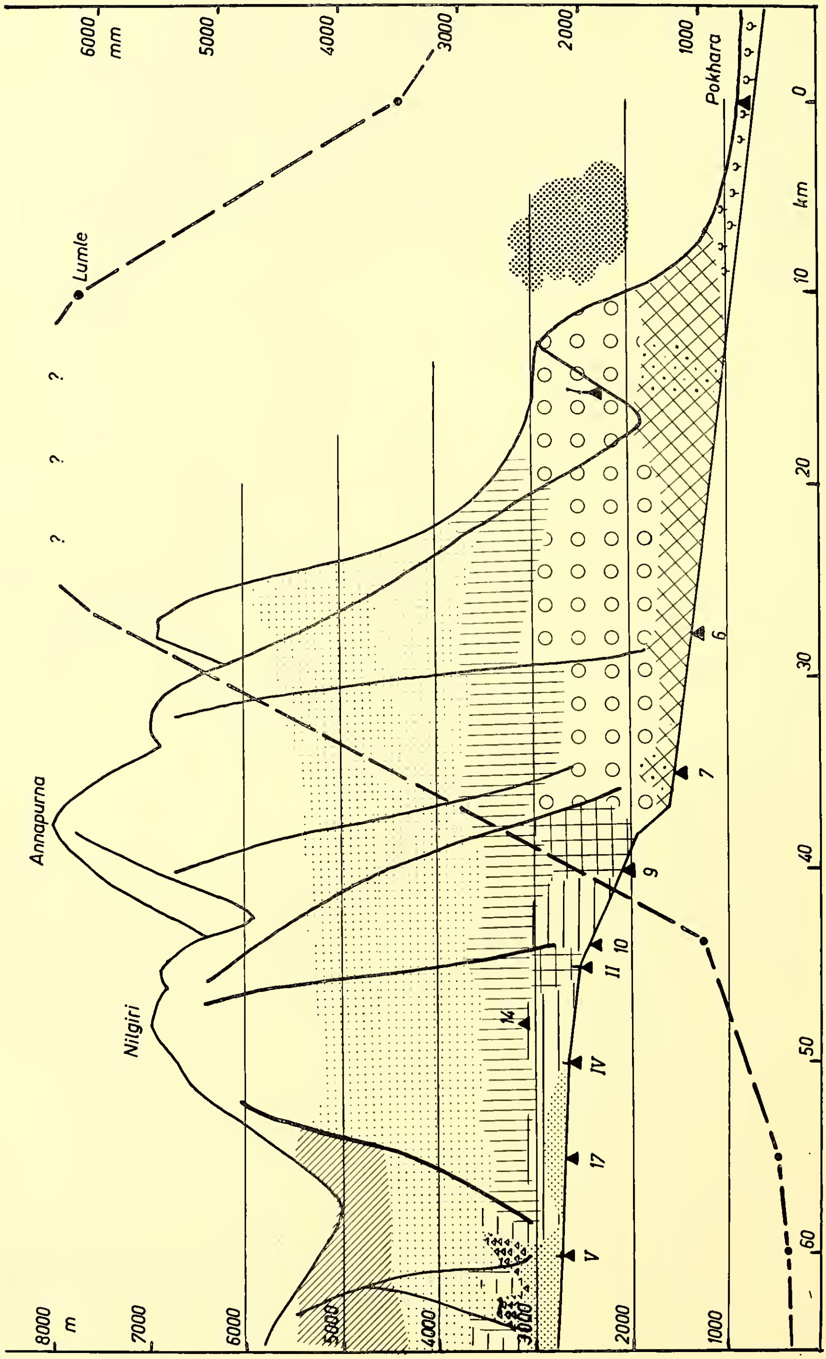
10
11



Annapurna
Nilgiri
Lumle
Pokhara
8000 m
7000
6000
5000
4000
3000
2000
1000
6000 mm
5000
4000
3000
2000
1000
0
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km
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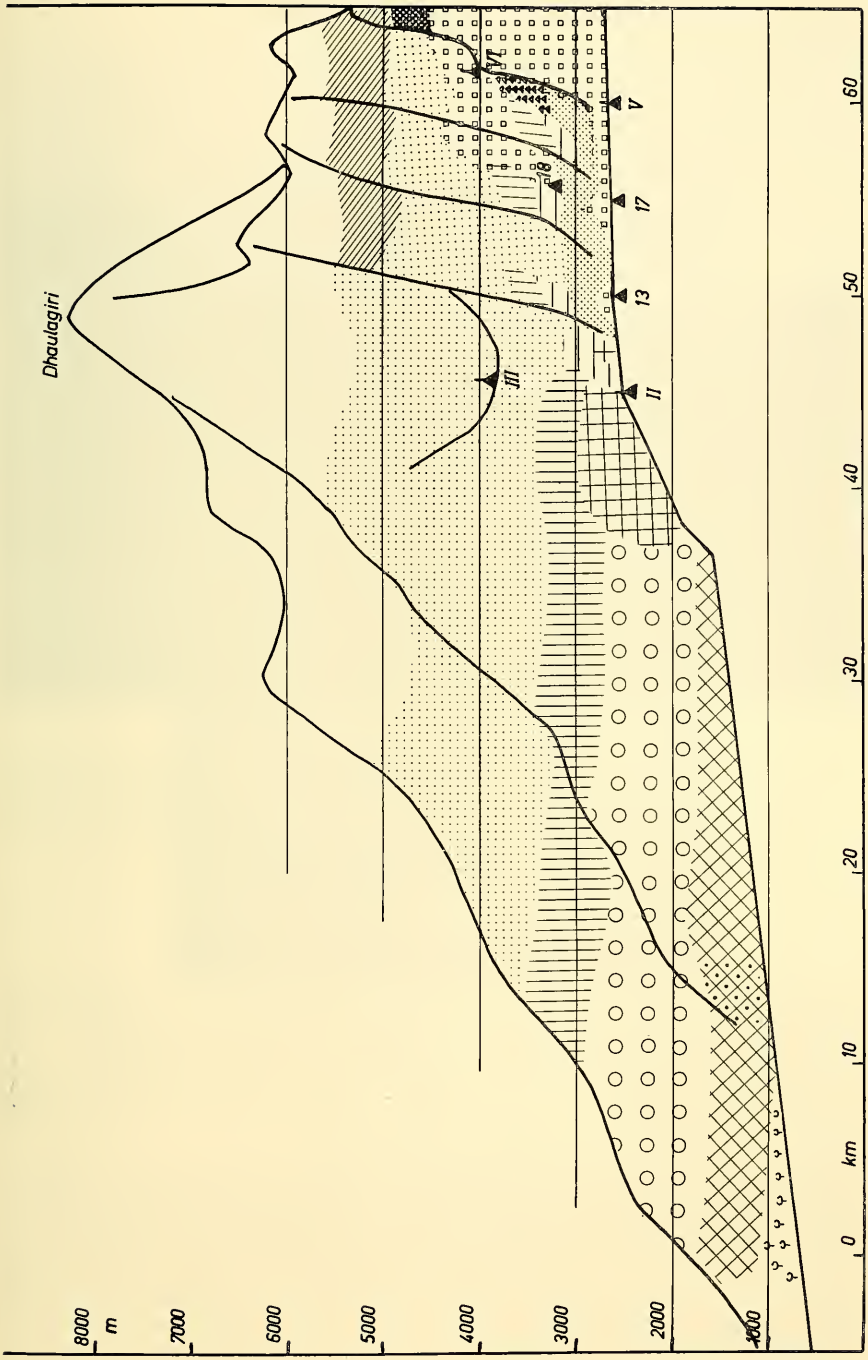

Dhaulagiri
8000 m
7000
6000
5000
4000
3000
2000
1000
0
10
20
30
40
50
60
km
II
III
13
17
18
V
VI

3.2 Camp 1, Kyumnu Khola valley, 2350 m, Fig. 1, 2: Nr. I; Fig. 3, 4

Fig. 3: Oak forest at Kyumnu Khola valley (2360 m).
In this type of forest there is much rainfall and longlasting fog. Predominating trees are *Quercus lammellosa* (partly cut), *Rhododendron arboreum*, Acer spp., *Magnolia*, heavy undergrowth of bushes like *Berberis, Mahonia, Viburnum, Daphne* etc. and many epiphytic plants like mosses, ferns and orchids. The small pastures are used for cattle and give place for thousands of leeches.

The situation is 5 km to the north-west of Ghandrung on the southern side of the Kyumnu Khola valley, which there runs in a west-east direction. Therefore the camp faces north. It was situated in the *Quercus lammellosa* forest on a small pasture just at the borders of rather original forest and secondary forest. The predominating species is *Quercus lammellosa*. There are also *Quercus lineata, Castanopsis tribuloides, Ilex dipyrena, Lyonia ovalifolia, Taxus wallichiana, Rhododendron arboreum, Prunus nepalenis* and *Acer* spp.

Smaller trees and bushes are *Mahonia nepaulensis, Viburnum erubescens, Arundinaria* sp., *Berberis nepalensis, Ribes* sp., *Brasseiopsis glomerulata, Torricellia tiliifolia, Daphne* spp., *Litsea oblonga, Dodecadenia grandiflora* and *Symplocos* sp.

Amongst smaller plants there are many epiphytic ones, like ferns and orchids, *Vaccinium retusum, V. nummularium, Rhododendron dalhousie, Aristolochia griffithi* and *Hedera nepalensis*.

About 100 m lower the zone of cultivation begins and there are a few specimens of *Schima wallichii* just starting flowering. Higher up, at 2500 m, there is a rather dense forest with *Quercus semicarpifolia*, *Rhododendron arboreum* and *R. barbatum*, *Magnolia campbelli*, *Ilex dipyrena*, *Daphne papyracea*, a few *Tsuga dumosa* and *Abies spectabilis*.

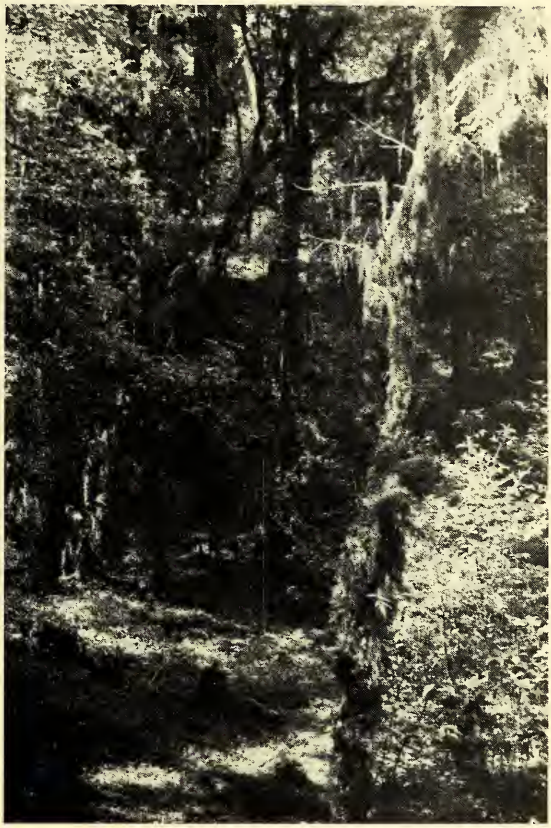


Fig. 4: Within the temperate moist forest (facies *Quercus lammellosa)* at the first forestcamp near Gandrung (southern slopes of Annapurna). Very humid biotopes of the agamid *Japalura* and several mice *(Rattus, Apodemus)* and shrews *(Soriculus)*.

The secondary forest is rather open and consists mainly of Lauraceae. The oak-forest has partly disappeared by leafcutting, partly by clearing for agriculture. Pasture is very common during most of the year and gives, in association with high humidity, an ideal background for millions of leeches, the most typical animal in this zone.

The same type of forest is found in the east at Arun and the Tamur river. It is also widely distributed in the Eastern Himalaya and Western China, and there is a similar type in the Malaysian area on the higher mountains. It is absent in Western Himalaya. This distribution makes it clear that many species occur here whose main area is much more easterly. The distribution also fits well with the high amount of precipitation.

3.3 The way from Kyumnu Khola to Kali Gandaki

The way from Kyumnu Khola to Gorepani leads over a ridge of 3100 m altitude. As mentioned before we find *Rhododendron arboreum*, in large areas together with *Acer* spp., *Arundinaria* sp., *Quercus semicarpifolia* etc. at 2500—2700 m. Then one reaches the belt of coniferous trees, which do not form pure forest, but are mixed up with many broadleaved trees due to high rainfall. There are *Abies spectabilis, Tsuga dumosa, Acer* spp., *Rhododendron arboreum, R. barbatum* and *R. campanulatum, Betula utilis, Cotoneaster* spp. and *Quercus* spp. This zone is at 2700—3100 m. At Gorepani there is an oak-forest, rather original in the upper parts, lower down rather finished by leafcutting. Still lower down most of the area is cultivated with remainders of *Schima wallichii* forest and *Alnus nepalensis* in wet places. The latter also covers the riversides.

3.4 The way through the Kali Gandaki valley

At Tatopani we cross the river on a bridge (1150 m) and follow the valley towards the north. The riverside is covered by *Alnus nepalensis* as far as any vegetation of this kind is possible. The same can be said for the valley sides which are very steep and therefore not covered with trees, or they are cultivated whereever it is possible. So the forests there are rather poor. Opposite to Dana we find an open forest of *Pinus roxburghii* and then at Kabre (1800 m) there are a few oaks just before reaching the gorge. Here is a rather abrupt change which indicates a new type of climate. The predominating tree here is *Pinus excelsa*; from the gorge to Kalopani it is still rather wet and *Pinus excelsa* is mixed up with many broadleaved trees like *Acer* spp. On unstable slopes which have water close to the surface there are sometimes pure thickets of *Hippophae salicifolia*, f. e. at Lete. This species replaces *Alnus nepalensis* which grows on similar soils south of the gorge. There are also a few *Tsuga dumosa, Taxus wallichiana, Aesculus indica* and *Betula alnoides.*

3.5 Camp 2, Kalopani-Dhumpu, 2500 m, Fig. 1, 2: Nr. II; Fig. 5, 6

The place is situated at the western side of the valley near the slopes coming down from Dhaulagiri. Here the humid *Pinus excelsa* forest ends and the dry type starts. The valley floor is covered with *Pinus excelsa* forest with a few *Sorbus cuspidata* and *S. foliolosa, Hippophae salicifolia, Viburnum cotinifolium* and *V. erubescens, Jasminum humile, Berberis asiatica* and *B. angulosa, Syringa emodi, Wikstroemia canescens,* species of *Salix, Cotoneaster, Philadelphus* and *Rubus.* Parts of the valley are cultivated and potatoes and corn grow well there. The slopes are covered with many broadleaved trees and *Tsuga dumosa, Abies spectabilis* and *Cupressus torulosa.* On the eastern valley side two ridges come down from the Nilgiris and these are very important for the distribution of rainfall during the monsoon period. Here, usually, the monsoon clouds stop penetrating

Fig. 5: Kalopani (2500 m) is a small village in a rather open forest of *Pinus excelsa* of semihumid type. The hill in background is part of a ridge which comes down from Nilgiris (in clouds) and which forms the first of the important "cloud-catchers" keeping away much rainfall from the area north of it. Towards the south the hill is covered with broadleaved trees.

Fig. 6: Instruments for meteorological observations at Kalopani: In the box a thermohygrograph, beside of this a rainfallmeter and an anemometer. These instruments are used for all camps. Behind the potatoe field there are *Pinus excelsa* and a few *Tsuga dumosa,* the plain is covered with *Cotoneaster, Berberis* and *Wikstroemia.* In background Tukche peak (6915 m).

into the upper valley, but still much rainfall occurs. This rainscreen effect can be seen also in the vegetation types; the southern slopes of the ridges are mostly covered with broadleaved trees, while the northern slopes are covered with conifers (Fig. 4, 7). From here towards the north there is dry *Pinus excelsa* forest with much *Cupressus torulosa,* but few broadleaved trees.

3.6 Camp 3, Southeast slope of Dhaulagiri 3600 m, Fig. 1, 2: Nr. III; Fig. 7, 8

Fig. 7: On the way to Daulaghiri-camp at 3000 m altitude we got a good glimpse of Kali Gandaki valley just north of Dhumpu, where a second ridge from Nilghiris almost close the valley and stops much of the monsoon clouds. Up to here we find broadleaved trees (f. ex. *Aesculus indica), Tsuga dumosa* and *Taxus.* North of this there is only dry forest of *Pinus* and *Cupressus.* Here is the gateway to the Palaearctic region.

Fig. 8: Heavily grassed pasture covered with marvelous primulas at the foothills of Dhaulagiri (3700 m). Tukche peak in background. Other parts are covered with low scrub of *Berberis.* Rhododendrons are almost absent.

While the valley center is usually kept free of clouds and, therefore, rather dry, the slopes above the valley floor are much more wet, especially at the places we visited on the side of Dhaulagiri. Here there are terracelike yak pastures at or above the treeline. Towards the north and west the area is surrounded by high mountains, Dhaulagiri and Tukche Peak, which act as rainscreens and bring heavy rainfall on the pastures. The annual amount must be very high. The vegetation is heavily influenced by the grazing animals and consists mostly of shrubs of *Juniperus squama-*

ta and *Berberis aristata* mixed up with *Lonicera* sp. Single bushes of *Rhododendron campanulatum* occur and a lot of *R. anthopogon* besides some *Salix* sp. Compared with the moist alpine slopes of the outer Himalaya, here the vegetation is already rather poor; remarkable few rhododendrons are present, but still a lot of primulas. The area is, therefore, of transitional charakter. Below the treeline there are scattered groups of *Abies spectabilis*, *Rhododendron arboreum* and *Arundinaria* sp. together with small shrubs of *Betula utilis*. It is evident that this forest is heavily influenced by man. *Meconopsis nepaulensis*, a fiery red form, was full flowering and one of the fascinating impressions we got there.

3.7 The way from Kalopani to Choklopani near Tukche[1]) Fig. 9

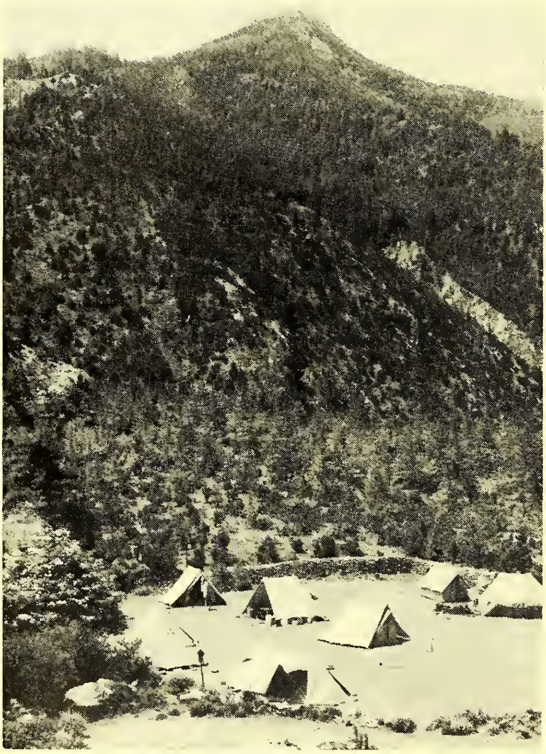
Fig. 9: At Choklopani looking towards south we can see the "monsoon-wall", stopped by the ridge near Dhumpu. Within a distance of a few kilometers rainfall decreases rapidly.

North of the Dhumpu ridge there occurs an abrupt change towards dry vegetation, which here consists mainly of *Pinus excelsa* mixed with *Cupressus torulosa*. Along the very flat riverbed there is a kind of steppe consisting of *Sophora moorcroftiana* and *Oxytropis sericopetala* or a *Caragana-Artemisia* facies. Fields are usually irrigated, while rainfield agriculture ends here. *Salix* sp. and *Populus* sp. grow along the fields and there are peaches and apricot trees, producing very

[1]) Officially spelled Tukucha, but always pronounced Tukche

tasteful fruit. The influence of the violent wind which blows during the daytime is very strong and keeps the valley center usually free of clouds and much more dry then the valley sides. Here, higher up, one can find remainders of the wet *Abies-Rhododendron-Betula* forest far more to the north then one would expect. It is not a large closed area anymore, but limited to localities of small size which are interrupted by *Pinus excelsa* and *Juniperus indica* which becomes much more common towards the north.

3.8 Camp 4, Choklopani near Tukche, 2600 m, Fig. 1, 2: Nr. IV; Fig. 10, 11, 12



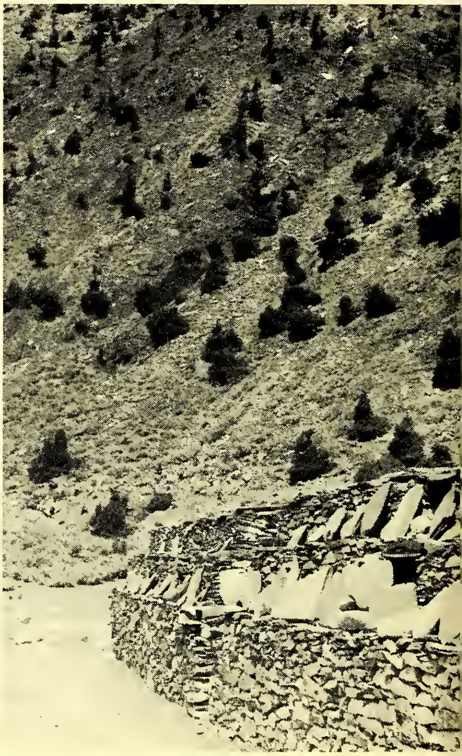


Fig. 10: At Choklopani north of Tukche (2600 m) we met a semiarid forest of *Cupressus torulosa* and *Pinus excelsa*. In small river valleys there is *Picea smithiana*. At moist places on the hill in background, Taksang, there are some *Abies spectabilis, Betula utilis* and *Rhododendron*. Here agriculture must be done by irrigation.

Fig. 11: A mani wall near Choklopani and remainders of *Cupressus*-forest on the slope. The low vegetation is composed by *Thymus, Sophora, Caragana* and *Artemisia*.

Fig. 12: A view from Taksang (3100 m) towards north. Scattered trees of *Cupressus* cover the valley sides and grow near Chhairo, a village in the middle of the valley. Higher up on the mountains there are *Pinus excelsa* and *Juniperus.*

The place is situated on a riverside terrace on the eastern side of the valley, where a stream comes down from the Nilgiri mountains. Here the valley floor is covered by a forest of *Pinus excelsa* and *Cupressus torulosa* together with some *Picea smithiana.* There are many small shrubs and herbs: *Caragana* spp., *Cotoneaster* spp., *Ephedra gerardiana, Jasminum* sp., *Rosa sericea, Clematis montana, Verbascum thapsiforme, Artemisia* sp., *Cornus capitata, Salix* sp., *Stellera chamaejasne* and *Thymus serpyllum.* The west banks of the Kali Gandaki river are covered by a steppe of *Sophora moorcroftiana, Oxytropis mollis, Artemisia stricta, Ephedra gerardiana, Lonicera* sp., and *Berberis* spp. In places above the valley floor there is much *Cupressus,* which higher up gives way to *Juniperus indica,* then *Abies spectabilis* and *Betula utilis* and finally a moist alpine zone.

Above Choklopani there is a summer village with some agriculture and pasture: Taksang, 3100 m. The vegetation there is similar to Kalopani, rather more humid than Choklopani. The forests up there are mixed up with *Abies, Pinus, Betula* and *Rhododendron arboreum.* Common bushes are *Rosa sericea* and *R. macrophylla, Ribes* sp., *Spiraea* sp., *Berberis, Artemisia, Verbascum* and *Thymus.* There are many flowers of *Ranunculus* spp. and *Anemone* spp. Here one can easily observe the greater degree of humidity compared with that of the valley floor. The reason for this is explained in the chapter dealing with meteorological observations. We visited this place a few times and did just a little collecting.

3.9 The way from Choklopani to Jomosom

The western slopes of the valley are now covered with an open forest with *Cupressus torulosa,* which higher up gives way to *Juniperus indica.* The trees disappear near Jomosom, but it seems that trees were formerly growing further to the north and have been distroyed by human influence. The riverbanks are covered with the same steppe flora, with *Caragana, Artemisia* and *Sophora.* Agriculture is limited and possible only by irrigation. On the eastern slopes there is still *Pinus excelsa* mixed up with *Cupressus* and higher up the same vegetation as at Taksang.

3.10 Jomosom, 2800 m, Fig. 1, 2: Nr. V; Fig. 13

Fig. 13: View towards north in the upper Kali Gandaki valley. In the middle of the picture the village Jomosom, on the right Tini. Remarkable the extremely arid situation of the valley.

The situation is very wind exposed. *Cupressus* has almost disappeared and we find a steppe of *Caragana, Artemisia* and *Sophora,* the later on the valley ground. There are a few bushes of *Rosa sericea* and around the houses peach trees and willows. On the east side there is agriculture on irrigated fields, surrounded by a richer flora of bushes like *Rosa sericea, Salix* and peaches. About 200 m higher up there are remainders of *Cupressus torulosa,* usually badly cut. In a steep gorge coming down on the west side we find *Cupressus, Juniperus indica,* many roses, *Sorbus*, peaches and, higher up, many old *Betula utilis*. Due to the wind Jomosom was not a very suitable collecting place. So we were looking for a better area which we found in Syang Khola valley which enters the main valley from the west.

3.11 Syang Khola valley, 2800—5200 m, Camp at 4000 m, Fig. 1, 2: Nr. VI, Fig. 14, 15, 16

Fig. 14: On our way to Syang valley at 3200 m we met with low bushes of *Cupressus* and *Juniperus indica*, scrubs of *Rosa sericea*, herbs like *Thymus*, *Caragana* and others. Monsoon clouds are finally stopped at one of the northern Nilgiri-ridges. Towards north there is bright sunshine, while in the south heavy clouds cover the area.

From the bottom of Kali Gandaki valley up to 200 m higher we just find scattered shrubs of thorny bushes, then a very open forest of *Cupressus* can be found which another 200 m higher is followed by *Juniperus indica* forming small trees. Here are plenty of *Rosa sericea*, some *Rosa macrophylla*, *Caragana* sp., *Thymus* and *Lonicera*. At about 3500 m one can find some fields growing potatoes. At about 3900 m, the timber line, there are, in small humid places, a few *Abies spectabilis* and *Betula utilis*, the outermost reminders of the widespread *Abies-Betula* forest of the southern slopes of Himalaya. *Rhododendron arboreum* is completely missing here. The flora mentioned can be found on the northern side of the valley which is exposed towards the south. The opposite side, which is cooler and more humid, carries *Cupressus* forest up to 3200 m, where it gives way to *Pinus excelsa* forest and, finally, to *Juniperus* with some *Abies* and *Betula*. Above the timberline there are much *Juniperus squamata*, *Berberis aristata*, *Lonicera* spp., *Caragana* spp. and a few rhododendrons, a small red flowering one, growing on moist soil. This type of vegetation is usually called *Caragana-Lonicera* steppe and ranges from 4000 m to 4600 m. Above this limit there is a type of meadows like the southern mountain side but much poorer, reaching up to 4800—4900 m, and consisting of many alpine plants. Higher up there is discontinuous high alpine vegetation. There is another type called xerophile alpine steppe, the limit of which is just at the border of the area we have seen, and extending towards the north.

Fig. 15: The camp in Syang valley (3950 m) is placed between low bushes of *Juniperus indica* and *J. squamata*, *Berberis aristata*, *Rosa sericea* and *Lonicera* spp. Only one species of *Rhododendron* was found on moist soil.

A good diagram of the distribution of all these elements is given by DOBREMEZ and JEST (1971, p. 180), in the vegetation map (Fig. 1) and in the cross section (Fig. 2).

We also visited a place called Old Marpha-Jhong, a little bit west of Marpha, 3100 m high and situated on the south slope of the valley which ends near Marpha.

Fig. 16: Rocky site in the Syang Kola valley at an altitude of 4500 m. Between the rocks in the foreground burrow systems of mousehares *(Ochotona)* and mountain-voles *(Alticola)*.

Here there is a good forest mixed of *Cupressus*, *Juniperus indica*, *J. squamata* and *Pinus excelsa*. There are many old fields covered with *Thymus* and many peach trees. Due to lack of water this village is not much used at this time.

4. General meteorological data

In order to get an impression of the climatic conditions we have collected data on temperature, humidity and rainfall from different places in Nepal. These data are not true climatological figures, their origin and the time intervalls are too different, but we consider them most helpful in explaining the biogeographic and ecologic phenomena we have studied in Central-Nepal. Combined with our observations and the vegetation zones in the area concerned they give quite good informations. So far as it is available we have choosen observation sites, which characterize different levels of altitude on the moist southern slopes of the mountains, the dry area in the north and the transition which occurs in the Kali Gandaki valley.

Meteorological observations were carried out by a thermohygrograph kept in a screen to avoid influences by irradiation and 1.70 m above ground. Temperature in ° C and relative humidity of the air were continuously recorded during the time of our stay at the different localities. At the same time we observed the rainfall by a simple rainmeter. The figures are given in mm. Regular observations on windspeed were done with an anemometer. For microclimatic observations see that chapter.

4.1 Temperature

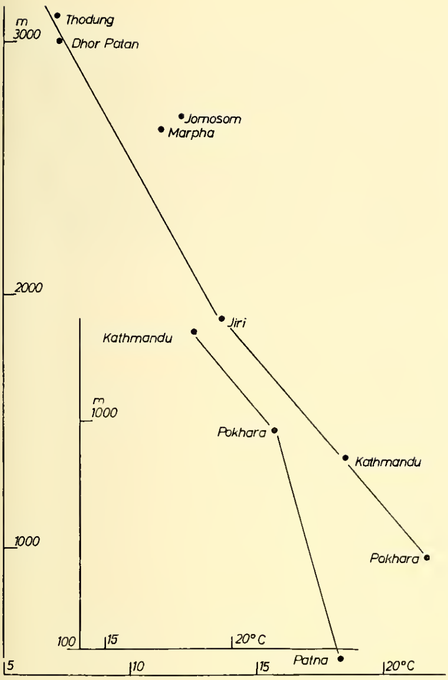
The average monthly and annual figures for temperature are collected in table 1 and demonstrated in diagram 1.

Table 1:

Average monthly and annual temperatures from different localities (° C)

month	Pokhara[1] 960 m	Kathmandu[2] 1350 m	Jiri[3] 1900 m	Kyumnu Khola 2360 m	Kalopani 2500 m	Choklopani 2600 m	Jomosom 2800 m	Jomosom[8] 2800 m	Thodung[10] 3100 m	Dhor Patan[9] 3000 m
I	13,5	9,7	5,5					4,7	0,9×	—1,1
II	15,3	11,6	7,2					5,2	3,0×	—0,9
III	19,3	15,5	12,2					9,0	5,8×	4,9
IV	23,2	20,0	14,8					12,0	9,3×	8,7
V	25,1	21,6	15,8	11,2[4]				14,7	10,3×	9,3
VI	25,3	22,6	19,3		15,0[5]	15,8[6]		19,0	11,3	13,0
VII	25,7	23,4	19,0				17,9[7]	19,3	12,3	14,3
VIII	25,4	23,1	19,2					19,0	12,1	14,0
IX	23,1	22,4	18,3					16,3	10,9	12,6
X	21,7	18,9	16,2					12,7	7,4	8,9
XI	16,9	14,4	10,5					7,7	3,0	1,5
XII	14,6	10,5	6,9					5,3	0,9	0,7
mean	21,7	18,7	13,7					12,0	7,1×	7,2

1) Observation time 1961—66, Climatological Records of Nepal. 2) 1901—40, ex Kraus, 1966. 3) 1964, ex Kraus, 1966. 4) Kyumnu Khola 2360 m, 13.—26. 5. 1973. 5) Kalopani 2500 m, 30. 5.—16. 6. 1973. 6) Choklopani-Tukche 2600 m, 18.—28. 6. 1973. 7) Jomosom 2800 m, 29. 6.—16. 7. 1973. 8) 1961—63, 1965—66, 1970, Climatological Records of Nepal. 9) Combined 1964 and 1965, ex Kraus, 1966. 10) VI—XII: 1963, ex Kraus, 1966. × figures very approximately estimated.



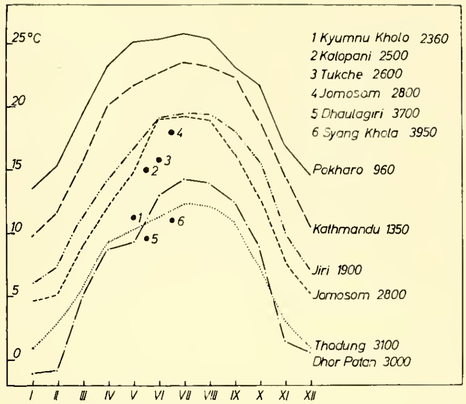


Diagram 1: Correlation between altitude and annual average temperature. The lower half is cut off and included.

Diagram 2: Average monthly temperature at different altitude.

The diagram shows quite clearly that the localities Pokhara, Kathmandu, Jiri, Thodung and Dhor Patan have a well fixed position within the temperature gradient estimated to 6° C per 1000 m difference in altitude; this gradient gives approximately a straight line on the diagram. Considering Patna in the Gangetic plain on one side and Jomosom and Marpha on the other side, the gradient is reduced. That means these places being out of moist adiabatic correlation between temperature and altitude. Thus the upper Kali Gandaki valley is 2° C too warm. This fact already indicates a different type of climate, supported further on by the annual distribution of rainfall, which will be considered in the next chapter. The reason for this phenomenon is discussed by FLOHN (1970) and will but briefly be mentioned here. The rainscreen effect by the Himalaya ridge gives much reduced cloudiness combined with strong irradiation almost all over the year and at the same time by Föhn-effect due to the usually blowing strong wind from the south an additional rise of temperature. Also the annual average difference of minimum and maximum temperature is much larger than at observation places on the southern slopes. Like this figure the annual amplitude is higher, which can easily be recognized from diagram 2 where the figures for June, July and August at Jomosom come close to those at Jiri, a station which is 900 m lower than Jomosom.

4.2 Wind

Like all other valleys which cross the Himalaya ridge the Kali Gandaki valley, especially in its northern parts, is influenced by a very strong southerly wind. The origin is discussed by FLOHN (1970): Strong irradiation on the Tibetan plains and the adiabatic liberation of energy is the origin of a strong air circulation, a thermic wind which is pressed through the narrow valley. It is strongest at the gorges. We made observations on some days with an anemometer and the figures are given in table 2. The same method was used for observations at Jomosom on the west bank of Kali Gandaki. Here figures out of five days are compiled in table 3.

Table 2:

Windspeed at Choklopani, 18. 6. 1973, m/sec

time	7.00	8.00	9.00	10.00	11.00	12.00		
medium	0	2—3	2—3	3—5	5—7	7—8		
maximum	0	6	6	8	10	13		
time	13.00	14.30	15.30	17.00	18.00	19.00	20.30	21.30
medium	7—9	7—9	6—8	6—8	5—10	6	2—3	0
maximum	13	14	12	12	15	10	5	0

Table 3:

Windspeed at Jomosom, 28. 6. — 2. 7. 1973, m/sec

time	10.00	12.00	14.00	15.00	16.00	17.00	18.00	22.00
medium	6	12	15	15	15	12	12	5
variation	4—10	8—16	10—20	10—20	10—18	7—16	7—16	4—6

Usually the wind starts between 09.00 and 10.00 h and lasts up to 24.00 or 01.00 h. On a few days, when the sky in the north is cloudy, the wind is less strong and stops already at 21.00 h. A change of wind direction towards cool wind down from the mountains was not observed. On our way to Syang Khola valley camp we noticed that higher up the wind speed decreases and at the camp site (3950 m) the maximum speed we observed was 5 m/sec. Here also occurs a change in direction; a cool wind blows downwards during night time. The valley wind is very regular and, as we were told by the local people, is blowing almost all the year except for a short time during winter. This regularity could easily be used to produce power by windmills.

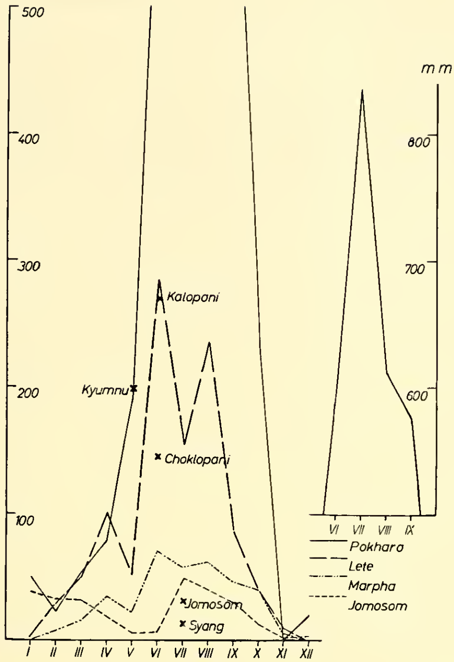


Diagram 3: Average monthly rainfall within the area between Pokhara and Jomosom. The maximum peak at Pokhara is cut off and enclosed to te right. Precipitation in mm.

In Nepal it is easier to get figures of rainfall than of temperature; therefore more data were available, even from the area of our research (diagram 3). Beside of this we made our own observations which are compiled in tables 4, 5. To get figures which in some way can be compared with the meteorological data, we have calculated the average daily rainfall each month of these data as well as of the periods of our observations, which give quite reasonable results.

The figures and the diagram show clearly the enormous amount of rainfall on the southern slopes with an, until now, unknown maximum of more than 6000 mm at Lumle[2]). Most rainfall occurs during monsoon time but also premonsoonal rainfall is noteworthy and a very small peak of winter rain; spring and autumn are usually very dry. General climatological considerations and vegetation show that the highest amount of rainfall is limited to the main level of condensation, that is between 1800 and 3500 m. The condensation brings an additional amount of

[2]) Lumle, a place midway betwen Khanre and Chandrakot.

Table 4:
Rainfall data from Central Nepal (mm)

month	Pokhara[1]) 960 m	Lumle[2]) 1700 m	Lete[3]) 2450 m	Marpha[4]) 2700 m	Jomosom[5]) 2800 m
I	51		3	0	33
II	23		29	8	30
III	53		51	18	28
IV	78		102	36	17
V	192		53	22	4
VI	585		285	71	19
VII	844		154	58	45
VIII	615		237	63	40
IX	571		87	46	30
X	229		42	42	13
XI	1		10	6	2
XII	21		0	0	3
total	3263	6170	1053	370	264

1) 1961—63, 1965—66, Climatological Records of Nepal. 2) 1970—71, ex KLEINERT. 3) 1971, Climatological Records of Nepal. 4) 1971, dito. 5) 1961—63, 1965—66, 1970, dito.

precipitation, which usually is not registered by the normal rainmeters, that is fog. KRAUS (1966) brings some figures from Thodung, 3100 m, East Nepal, which give us an idea of the amount of this precipitation. In 1963 rainfall was registered by the normal method and at the same time precipitation with "fogcatcher" sec. GRUNOW. The figures are given below.

month	VI	VII	VIII	IX	X
rainfall normal	518	772	938	370	139
with "fogcatcher"	601	1010	1152	418	150
excess amount in %	14	24	19	12	7

It is very impressive to see that up to 24 % more water is available for living beings, a fact which usually is not considered when based on rainfall accounts with normal method only. The great abundance of fog not only influences vegetation but

Table 5:

Average daily rainfall in Central Nepal (mm)

month	Pokhara[1] 960 m	Kyumnu Khola 2360 m	Lete[3] 2450 m	Kalopani 2500 m	Choklopani 2600 m	Marpha[7] 2700 m	Jomosom[8] 2800 m	Jomosom 2800 m	Syang Khola 3950 m
I	1,63		0,1			0	1,26		
II	0,83		1,0			0,29	1,21		
III	1,72		1,6			0,58	1,07		
IV	2,6		3,4			1,2	0,63		
V	6,2	6,5[2]	1,7			0,73	0,2		
VI	19,5		9,5	2,2[4]		2,4	0,23		
VII	27,24		4,95	13,8[5]	4,6[6]	1,9	1,46	1,00[9]	0,4[10]
VIII	29,53		7,9			2,1	1,35		
IX	19,03		2,9			1,5	0,94		
X	7,4		1,35			1,35	0,44		
XI	0,04		0,35			0,2	0,06		
XII	0,67		0			0	0,14		

1) 1961—63, 1965—66. 2) 13.—26. 5. 1973. 3) 1971. 4) 30. 5.—10. 6. 1973. 5) 11. 6.—16. 6. 1973. 6) 18.—28. 6. 1973. 7) 1971. 8) 1961—63, 1965—66, 1970. 9) 29. 6.—16. 7. 1973. 10) 3.—11. 7. 1973.

also animal life, especially distribution of species. This problem will be dealt with in a separate paper, but we should mention here the enormous reduction of sunshine hours due to fog and the distribution of heliophilous animals, for example butterflies.

We must also mention snowfall, which usually occurs above the 3000 m level and even lower down, but there it does not last very long. Snowfall is also quite common at Jomosom during January and February. This fact, and the high amount of rainfall during wintertime, give Jomosom quite a different aspect; it does not belong to the Indian type of climate which predominates on the southern slopes. Observations in 1958-66 show that the month with highest rainfall is January 2 times, February 1, March 1, but July only 1 and August 3 times (Dittmann, 1970). Here the influence of the depressions which come from the west during winter is significant. They also bring some winter rain towards the south but there, in relation to the high amount of summer rain, the total of winter rain is very small.

For biological studies it is of interest to know the annual distribution of aridity and humidity. Simply expressed arid months are those where evaporation is in excess and humid ones those where precipitation exceeds. Generally many factors are influencing this aspect and many authors have discussed the problem, for example also by using facts of phytogeography, but we will only use a simple formula which in an empirical way was given by WALTER and LIETH (1960). This states that there is an arid month when $(3t\text{-}N) > 0$ and humid when $(3t\text{-}N) < 0$. t is the monthly average temperature in °C and N the precipitation in mm. The factor 3 has been found by experience to be suitable for application in Nepal.

Table 6:

Distribution of aridity (a) and humidity (h) at different places

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	annual aspekt
Pokhara	h	a	a	a	h	h	h	h	h	h	a	a	h
Kathmandu	a	h	a	a	h	h	h	h	h	a	a	a	h
Jiri	a/h[1])	a/h[1])	h	h	h	h	h	h	h	h	a	a	h
Jomosom	h	h	a/h[1])	a	a	a	h[2])	h[2])	a	a	a	a	a

[1]) The precipitation of these months changes much, so in some years they have an arid aspect, in others a humid.

[2]) The figures concerning these months are at the limit between arid and humid. The observation time is too short to give a more exact decision. Judging from other factors like vegetation, irradiation and windconditions we think of these months as being almost arid.

With increasing altitude the humid time extends due to increasing rainfall and decreasing temperature. This gradient concerns the southern slopes. Along the Kali Gandaki valley towards the north, the aridity extends and the general aspect humid-arid changes at a line north of Dhumpu-Larjung. Beside the natural vegetation where broadleaved trees disappear another fact indicates this change: agriculture depending on rain ends at Larjung. Further to the north there are only irrigated fields.

4.4 Relative humidity

Data on relative humidity from Nepal are very scarce and they include usually no continuous registrations. The figures are calculated out of observations at certain hours, Kathmandu for example at 08.00 h and 17.00 h. KRAUS (1966) has published figures from Jiri, Thodung and Dhor Patan. These depend on continuous registration by hygrograph. Ours, which are compiled in tables 7-10, do also. The figures we have obtained are rather high at all places, especially at Kyumnu Khola in the fog forest above the level of condensation; but also at the other places, not least at Jomosom. Here we have, as already mentioned, an amount of dew the size of which we unfortunately do not know. But even when the dew brings additional water, the influence of this seems to be not very large, due to the strong wind and the irradiation during daytime. But its effect on temporary microclimatic conditions should not be neglected. Our microclimatic observations point out the same.

Table 7:

Meteorological observations at Kyumnu Khola valley camp, 2360 m, 13.—26. 5. 1973

date	temperature ° C			relative humidity %					rainfall mm
	average dayly	minimum	maximum	average dayly	minimum	maximum	8 h	17 h	
13. 5.	11,8	5,8	20,4	83	50	100	62	94	
14. 5.	11,0	8,2	17,0	96	75	100	90	98	
15. 5.	11,3	8,0	20,2	94	65	100	80	90	
16. 5.	12,4	6,7	21,0	89	62	100	81	87	0
17. 5.	12,3	6,5	21,2	80	50	100	67	56	6,0
18. 5.	9,2	5,8	16,5	91	67	100	85	96	11,8
19. 5.	9,3	5,0	18,6	88	58	100	65	88	5,5
20. 5.	9,5	4,9	18,1	93	62	100	72	100	6,6
21. 5.	10,2	6,2	16,0	95	82	100	89	96	3,3
22. 5.	11,8	7,0	18,6	93	71	100	80	96	2,0
23. 5.	11,2	8,4	15,5	97	86	100	97	96	2,4
24. 5.	12,3	7,6	16,6	96	84	100	92	94	1,0
25. 5.	13,1	11,0	18,3	95	82	100	96	98	12,7
26. 5.									20,0
mean	11,2	7,0	18,3	91	69	100	81	91	71,3 total

Temperature: Absolute maximum 21,2° C, absolute minimum 4,9° C. Relative humidity: Absolute maximum 100 %, absolute minimum 50 %. Average daily rainfall 6,5 mm.

The average daily difference in temperature is 11,3° C.

Weather conditions: Usually the mornings up to noon are clear with bright sunshine, later on cloudiness increases by convection combined with thunderstorms and shortlasting heavy rainfalls. As a rule temperature now rushes down very quickly and the area is fogcovered until late in the night. This type of thunderstorms are well known to give the premonsoonal precipitation on the southern slopes of Himalaya and the common fogs almost all over the year originate in the altitude of average condensation of clouds. Fog gives an utterly precipitation of 10-25 % more compared with usual rainfall figures. The high and steady humidity in this way gives rise to the very typical evergreen fog-forests with its rich epiphytic flora and millions of leeches, which make this wonderful looking area the most uncomfortable one in the country.

Table 8:

Meteorological observations at Kalopani camp, 2500 m, 30. 5. — 16. 6. 1973

date	temperature ° C			relative humidity %					rainfall mm
	average daily	minimum	maximum	average daily	minimum	maximum	8 h	17 h	
30. 5.									0
31. 5.	14,4	7,1	21,0	76	47	100	63	57	0
1. 6.	13,5	7,1	20,9	75	45	100	50	63	1,0
2. 6.	13,3	8,2	22,1	85	52	100	64	97	4,0
3. 6.	14,5	7,1	22,6	75	45	198	60	70	0
4. 6.	14,8	9,2	20,4	81	58	100	62	70	0
5. 6.	16,2	12,0	21,0	86	61	100	81	70	1,0
6. 6.	15,9	14,0	20,2	93	72	100	85	92	1,0
7. 6.	15,5	13,0	20,4	94	75	100	92	90	13,5
8. 6.	13,8	11,0	16,9	95	78	100	94	84	4,3
9. 6.	15,1	11,1	19,0	91	75	100	82	84	0
10. 6.	16,1	11,0	22,0	87	60	100	71	94	0
11. 6.	16,5	14,0	21,1	90	68	100	76	96	8,5
12. 6.	15,6	13,5	19,2	95	80	100	80	94	8,0
13. 6.	14,9	14,0	18,2	96	82	100	99	96	9,0
14. 6.	14,8	12,8	18,2	96	81	100	100	83	15,7
15. 6.	15,1	14,4	15,6	99	97	100	98	100	10,0
16. 6.									30,0
mean	15,0	11,2	19,9	88	55	100	72	84	110,0

Temperature: Absolute maximum 22,6° C, absolute minimum 7,1° C.
The average daily difference in temperature is 8,7° C.
Relative humidity: Absolute maximum 100 %, absolute minimum 45 %.
Average daily rainfall 30. 5.—10. 6. is 2,2 mm, 11. 6.—16. 6. is 13,8 mm.

Weather condition: During the first period quite small cloud amount in the afternoon after bright mornings. Very little rainfall resulting in convection thunderstorms, which seem to have their uppermost limit here. At 11th onset of monsoon, air pressure goes down, the altitude meter shows 150 m more! Now a tight cloudcover is outspread and longlasting rainfalls take place, which bring high humidity and small figures in daily differences of temperature and humidity. Quite a lot of leeches are now active even here. That shows that humidity at least during wet season is still high enough to give these animals a chance to survive.

Table 9:

Meteorological observations at Choklopani near Tukche, 2600 m, 18.—28. 6. 1973

date	temperature ° C			relative humidity %					rainfall mm
	average daily	minimum	maximum	average daily	minimum	maximum	8 h	17 h	
18. 6.	14,7	12,4	18,4	86	69	100	79	80	1,0
19. 6.	14,2	12,0	18,0	91	71	98	87	82	4,0
20. 6.	14,2	12,0	18,0	91	72	99	86	73	10,7
21. 6.	14,8	12,0	18,8	88	65	100	94	76	8,0
22. 6.	15,5	13,2	19,0	92	71	100	85	98	1,0
23. 6.	16,4	12,9	23,2	83	59	100	82	81	18,3
24. 6.	17,1	13,0	24,1	85	58	100	80	84	0
25. 6.	18,4	14,0	24,8	84	56	100	85	73	1,0
26. 6.	17,5	14,0	24,0	84	56	100	91	64	1,0
27. 6.									6,0
28. 6.									1,0
mean	15,8	12,8	20,7	87	64	100	85	79	49,6

Temperature: Absolute maximum 24,8° C, absolute minimum 11,8° C.
The average daily difference in temperature is 7,9° C.
Relative humidity: Absolute maximum 100 %, absolute minimum 64 %.
Average daily rainfall 4,9 mm.

Weather conditions: The ridges south of Choklopani give a remarkable rainscreen effect with much less rainfall and usually no clouds over the valley. Monsoon progresses very seldom further to the north combined with rainfall, which usually happens during night time when the normally quite strong valleywind stops. On the other side, by convection, the slopes higher up and the high mountains beside the valley are often cloudcovered and receive much a higher amount of precipitation, which is resulting in moist alpine conifer forest and moist alpine scrub similar to those growing on the southern slopes (see chapter on vegetation).

Table 10:

Meteorological observations at Jomosom, 2800 m, 29. 6. — 16. 7. 1973

date	temperature °C			relative humidity %					rainfall mm
	average daily	minimum	maximum	average daily	minimum	maximum	8 h	17 h	
29. 6.	17,2	13,2	22,5	77	52	96	82	67	1,0
30. 6.	17,7	14,0	23,2	79	53	97	86	62	0
1. 7.	18,9	13,6	24,6	75	48	100	65	53	0
2. 7.	19,4	12,8	25,5	69	42	98	78	52	0
3. 7.	19,4	14,0	25,4	66	41	87	61	57	
4. 7.	19,2	15,0	24,2	77	52	96	90	60	
5. 7.	16,3	13,8	21,6	81	52	98	83	72	
6. 7.	17,8	13,2	22,8	72	50	96	74	57	
7. 7.	17,4	13,5	22,8	75	53	93	83	66	
8. 7.	18,3	14,5	23,4	72	54	90	84	59	
9. 7.	16,8	13,6	22,4	77	54	96	78	70	
10. 7.	16,7	10,2	22,5	75	50	97	78	56	total out of
11. 7.	15,9	10,6	22,6	84	52	100	100	67	3.—12. 7.
12. 7.	17,5	11,2	24,4						6,0
13. 7.	17,7	14,2	23,4						9,3
14. 7.	18,2	14,0	24,2						1,0
15. 7.	19,4	15,4	25,8	71	41	95	69	57	0
16. 7.	18,8	15,0	24,2	74	48	95	71	66	
mean	17,9	13,4	23,6	75	49	96	79	61	17,3 total

Temperature: Absolute maximum 25,8° C, absolute minimum 10,2° C.
The average daily difference in temperature is 10,2° C.
Relative humidity: Absolute maximum 100 %, absolute minimum 41 %.
Average daily rainfall 1 mm.

Weather conditions: Normally a very strong wind (see that chapter) blows from the south and keeps the valley center free of clouds so there is much insolation even during monsoontime. This strong insolation and the wind keeps the area dry and somewhat warmer which will be shown in the chapter on general meteorological conditions. Like the lower parts of the valley even here the high mountains get some more clouds but not to such an extent as we saw at Kalopani and Choklopani. It should also be observed that the relative humidity is quite high and often reaches the dew-point during the calm night time.

4.5 Climatypes

Köppen and Geiger (1954) have elaborated a very instructive system of climatypes which will be used here. In agreement with Kraus (1966) all climatypes on southern slopes up to the treeline are climates of type C. That means warm temperate rain climates, coldest month between + 18°C and — 3°C, warmest more than 10°C. Up to 1800 m there is a Cwa-climate (w means dry season during wintertime, a means warmest month more than 22°C).

1800—3300 m: there is Cwb-climate (b means warm summer, monthly maximum below 22°, but least 4 months above 10°C).

3300—4000 m: there is Cwc-climate (c means only 1—4 months more than 10°C, coldest month more than — 38°C).

Above 4000 m up to ca 5500 m is the climate of E-type, the type which is common to areas without trees due to temperature. All months are below 10° C, to keep trees growing there must be at least one month with more than 10°C average. So it is quite easy to define this line.

Concerning Jomosom we find quite a different type of climate as mentioned already. The formula given for the borderline between rain climate and dry climate is $r = 2t + 14$. r is precipitation in cm, t is annual average temperature and 14 is a factor to be used when summer and winter have approximately the same rainfall.

$2t + 14 - r > 0$ means dry or steppe climate, type B

$2t + 14 - r < 0$ means rain climate, type C.

Using the formula for Jomosom there is: $t = 12$ and $r = 26$

$24 + 14 - 26 = 12$: that is arid, type B.

This type of climate is here called Bsk, steppe climate, where k indicates the annual average temperature less than 18°C, but warmest month more than 18°C. It seems clear that out of these considerations, the figures given before, the vegetation and the faunistic data, which will be published in a separate paper, Jomosom indicates that type of special steppe climate which can be found in the inner valleys of Tibet and in the West Himalaya.

4.6 The bioclimatic division of the southern slopes

The considerations we bring here cover only the southern slopes of the main range within an area between Annapurna and Likhu Khola in the east. Bases on temperature data we have obtained from places at different altitude, so we could calculate a correlation between altitude and air temperature. Now we can try to find out the limits of the vegetation zones. It must be pointed out that this procedure is a very rough one, but we hope to give some information concerning the climatic conditions of the vegetation zones we have studied. A similar method was applied by Mitsudera and Numata (1967), but the results do not correspond well with ours.

The first limit is at about 1000 m, where the sal-forest usually ends. It seems to be a little above the 20°C-isotherm. The climate is mostly called subtropical, using Köppens system it is Cwa. It is also called tropical Shorea forest.

The next limit will be found at about 1800 m, the upper border of the *Schima-Castanopsis* forest (wet subtropical forest), corresponding with the 15°C-isotherm. The climate is mostly called warm-temperate and after Köppen still Cwa.

The next line is at 2800 m, the 10°C-isotherm, where the evergreen oak forest ends. The climate of this belt is called warm temperate or temperate (MITSUDERA and NUMATA). In KÖPPENS system it is Cwb. Up to 3300 m there is the belt of coniferous trees, the upper limit of KÖPPENS Cwb, and the climate is called cold temperate. The treeline is between 3800 and 4200 m and corresponds with the 5°C-isotherm, the upper limit of Cwc-climate. This belt is the subalpine one and the climate is called cold temperature or subarctic. From here to the permanent snowline is the alpine belt with arctic climate and KÖPPENS E-type. Its upper limit does not exactly correspond with the 0°C-isotherm; influences of exposure and radiation are very important. But we can say that the permanent snowline is between 5200 and 5800 m, much higher than MANI states (1962), and rather more than MITSUDERA and NUMATA (1967). From the treeline up to 4800 and 5200 m there are alpine meadows, further on to the snowline is a high altitude discontinuous vegetation.

It can easily be seen that there are differences in nomenclature and limitation of the climatic zones according to the different authors. It is not the place to discuss these problems here, we just want to point out that the phytographic zonation seems to be the most suitable system for our bioclimatic purpose.

4.7 Vegetation zones and climatic data

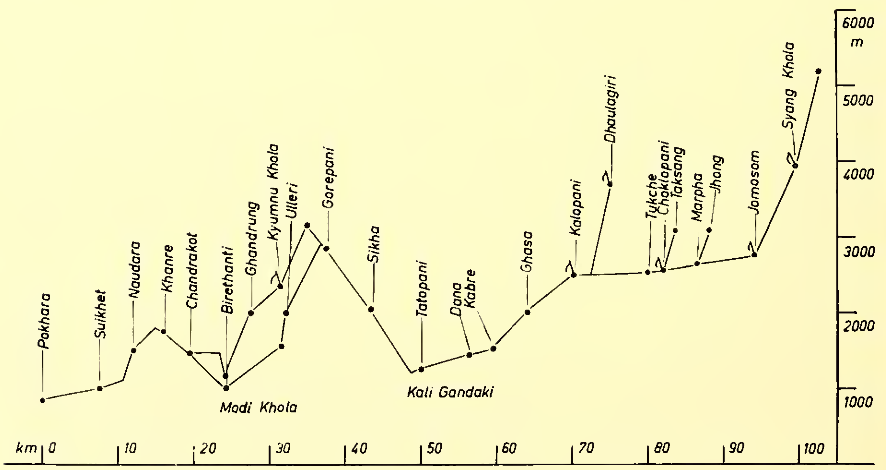


Diagram 4: A way diagram from Pokhara to Jomosom. The altitude is much multiplied.

The most important factor in the transition from moist to dry types of vegetation is of course the amount of precipitation. On the way from Pokhara to Jomosom one can see this change very easily, and a system of forest types has been elaborated. We have also obtained some useful figures of precipitation from this area so we can try to find an approximative correlation between these two phenomena.

The really dry, arid zone is limited to the lower parts of Mustangbhot starting at Kagbeni but not reaching the higher parts of the mountains which surround this area. It is a treeless steppe, the limitation of which seems to be the 250 mm-line of precipitation. We think the continental treeline to be at this level.

The area between 250 and 500 mm seems to be dominated by *Cupressus torulosa* forest, it is most clearly represented along the way from Tukche to Jomosom. Also *Juniperus indica* seems to be an indicator for this arid type of forest.

The forest of *Pinus excelsa,* either pure or mixed up with *Cupressus* may correspond to a precipitation between 500 and 1000 mm and can be unterstood as semiarid.

The moist part of *Pinus excelsa,* which is mixed up with broadleaved trees, may have a precipitation of 1000—1400 mm. At a lower altitude a similar type is represented by *Pinus roxburghii* with a similar amount of precipitation, growing on southerly exposed slopes, for example near Dana. It may be called semihumid. Finaly at more than 1400 mm all forests are of the humid type and cover almost all the area of the southern slopes.

Based on the formula for humidity and aridity by Köppen we can estimate 500 mm as borderline between his B and C climates. This agrees quite well with the vegetation zones.

5. Measurements on microclimate in the 4 main biotopes

As far as we know investigations on microclimatic conditions in the Nepal Himalaya are missing. In order to collect more informations about the life-conditions of groundliving animals and to get a better understanding of many of the distribution patterns we measured temperature and air-humidity in different biotopes, such as under rocks or bushes. The measurements were carried out with thermoscript instruments for taking down the temperature and with hygrometers. Whereas the thermoscript instruments recorded the temperature line over the course of several days, the hygrometer had to be controlled by varying random checkings. The lines of main temperature and main air-humidity were noted by a thermohygrograph installed in a transportable weather station at the various camps (Fig. 6).

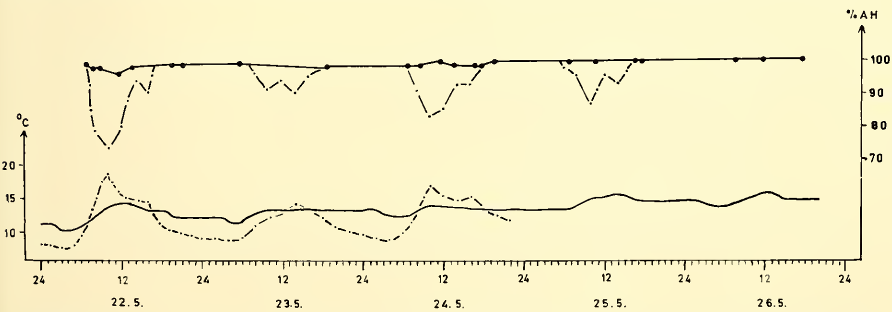


Diagram 5: Temperature (unbroken lower line) and air-humidity (unbroken upper line) slightly underneath a rock on the ground of the rainforest in the Kyumnu Kola valley, 2360 m. Broken lines indicate additionally the main air-humidity measured by the camp's weather station.

The diagrams 5—9 compare the conditions under rocks at the localities of our main working camps. On diagram 5 the thermoscript was placed under a rock on the ground of the temperate oak forest in the Kyumnu Khola valley at 2360 m, a biotope especially inhabited by mice (for instance *Apodemus ghurka* or *Rattus fulvescens)* and by shrews (for example *Soriculus nigrescens, S. caudatus* or

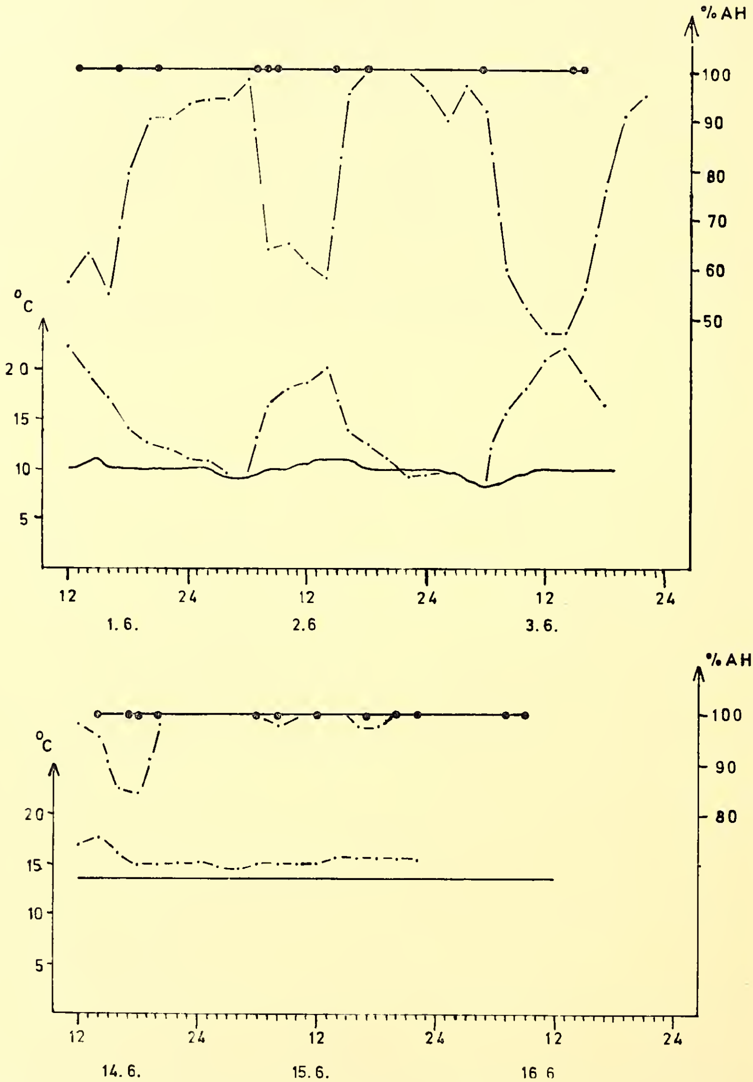


Diagram 6: Temperature (unbroken lower line) and air-humidity (unbroken upper line) deeply underneath a rock in Kalopani, 2500 m. Broken lines indicate additionally the main temperature and the main air-humidity measured by the camp's weather station. above: just before monsoon; below: right after the beginning of monsoon.

S. leucops). Due to the daily rainfall caused by convection the air-humidity was very high, permanently around 100 % as the line indicates. The temperature too was highly balanced, with rather slight differences between noon and night. The broken lines of main air-humidity and main temperature show peaks just before noon on every day very regularly. This effect is due to intense sunshine at this time

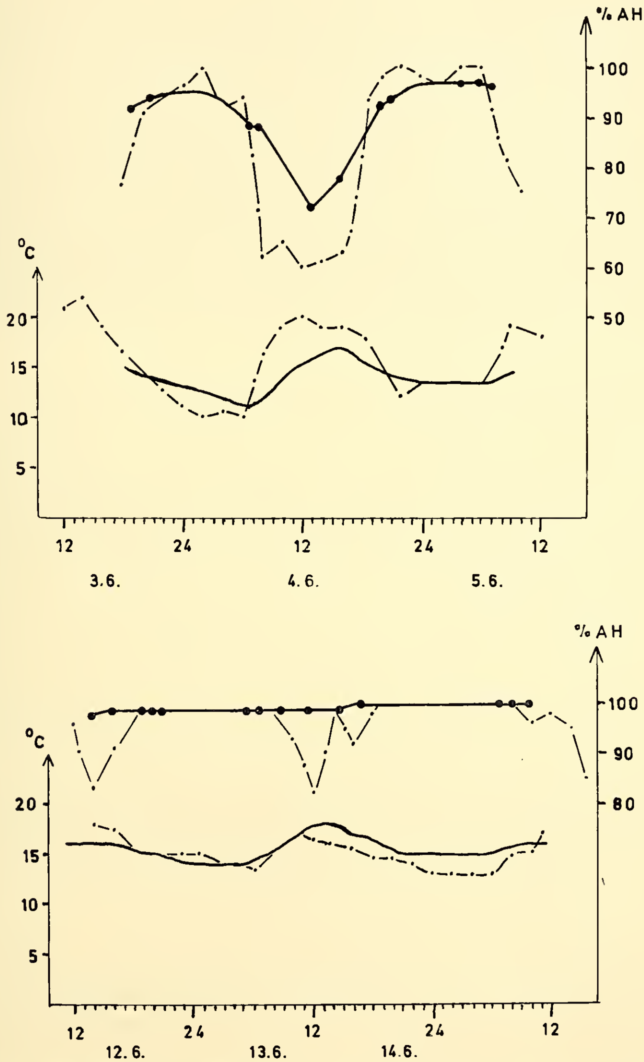


Diagram 7: Temperature (unbroken lower line) and air-humidity (unbroken upper line) underneath an open, single rock in Kalopani, 2500 m. Broken lines indicate additionally the main temperature and the main air-humidity measured by the camp's weather station. above: just before monsoon; below: just after the beginning of monsoon.

but it does not influence the conditions under the rock. These microclimatic observations obtained at the special place under the rock can be transferred on a large scale to the conditions on the ground of the temperate rain forest as a whole for the premonsoon-monsoon period. Therefore they are valid for all groundliving animals, for mammals as well as for amphibians, reptiles and insects.

Diagram 6 shows the same kind of measurements as diagram 5, this time carried out underneath a rock in a semihumid pine forest just behind our camp at Kalopani. The conditions under the rock are as balanced as in the Kyumnu Khola valley. The main airhumidity and the main temperature, however, are much more varying before the monsoon (diagram 6 a) than after the first monsoon-rainfalls (diagram 6 b). This is certainly due to the effect of sunshine and of covering with clouds respectively. It is obvious that the temperature under the rock is raised 3° to 4° C after the beginning of the monsoon, while the main temperature remains constantly balanced about 2° C above these values. If the measurements are carried out under a more open rock, where solar irradiation and daily fluctuation of temperature and humidity can influence the results, the values represent themselves a little more unbalanced (diagram 7). But still we realise especially the high level of air-humidity. Those conditions are valid for the same kinds of animals as noted before.

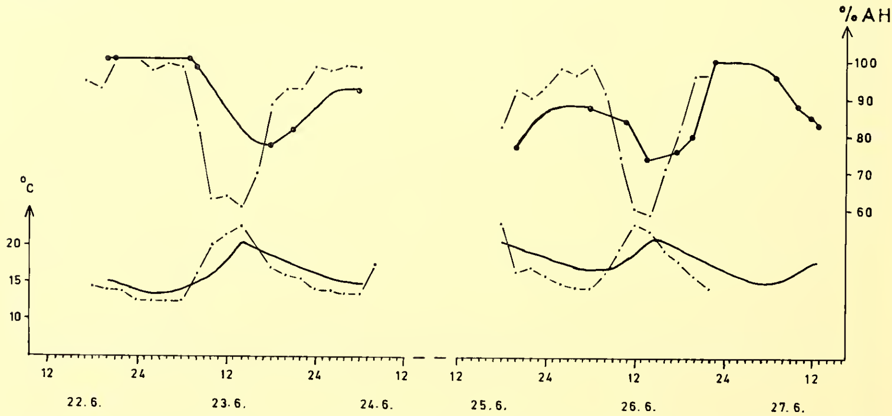


Diagram 8: Temperature (unbroken lower line) and air-humidity (unbroken upper line) slightly underneath a rock on the ground in Choklopani, 2600 m. Broken lines indicate additionally the main temperature and the main air-humidity measured by the camp's weather station.

With the camp at Choklopani we entered a region of much drier climate. This is expressed by varying course of lines for airhumidity and temperature in diagram 8. Although the measurements on this place were again carried out in the shadow underneath a big rock, the lines of microclimatic values now follow more distinctly those of the main conditions. But it should be remarked that both the temperature and the air-humidity under the rock do not undergo the same heavy oscillation as do the main climatic measurements. This means, especially in the case of humidity, that even at noon there remains a moisture of more than 70 %.

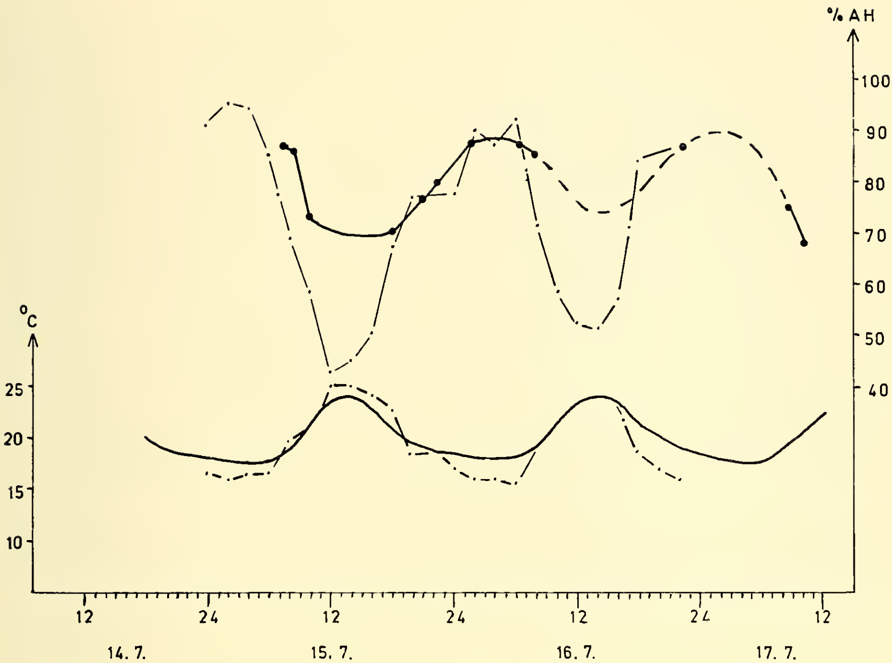


Diagram 9: Temperature (unbroken lower line) and air-humidity (unbroken upper line) underneath a rocky block, covered with earth, in Jomosom, 2700 m. Broken lines indicate additionally the main temperature and the main air-humidity measured by the camp's weather station.

The observations at Choklopani are still more impressive when we look at diagram 9, showing the results of measurements under a rock at Jomosom. Here we have reached the real dry districts of the upper Kali Gandaki valley and as the rock no longer could be choosen at a shadowy, hidden place in forests, it has been covered with a layer of earth in order to prevent the falsification of results by solar irradiation. Both the lines of temperature now are almost identical, but the air-humidity remains considerably higher under the rock than in the open air. The low rate of main air-humidity during noontime is certainly not only the consequence of solar irradiation but is also due a great deal to the strong daily wind. In connexion with the climatic change from wet to dry conditions in the upper Kali Gandaki valley we found an expected change of groundliving fauna in mammals as well as in reptiles, amphibians and insects. Looking again at diagram 9 it seems surprising to note rather high values of microclimatic air-humidity (90 % and more) during the night, which under the rock remains around 70 % even at noon, the time of highest solar irradiation and strongest wind. Certainly this humidity also during the day time enables animals with a greater need for humid surroundings, such as frogs, to spread over their area of distribution and to reach their special habitats such as permanent or temporal waters.

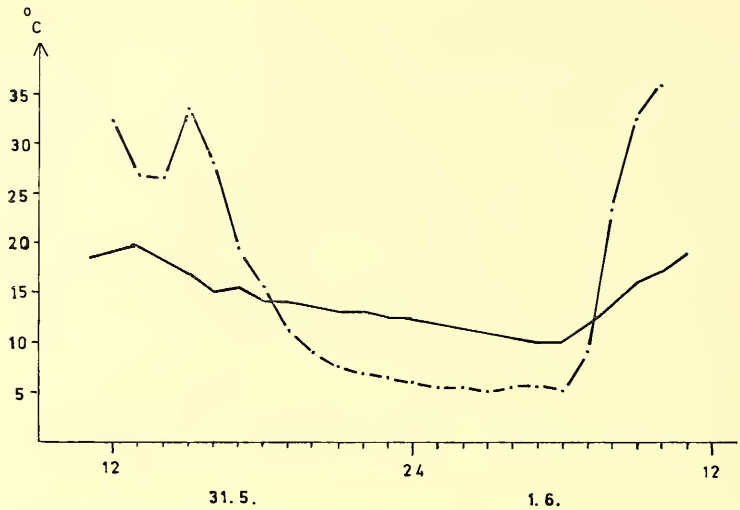


Diagram 10: Temperature underneath dense bushes (unbroken line) and temperature of solar irradiation on the ground (broken line) in Kalopani, 2500 m.

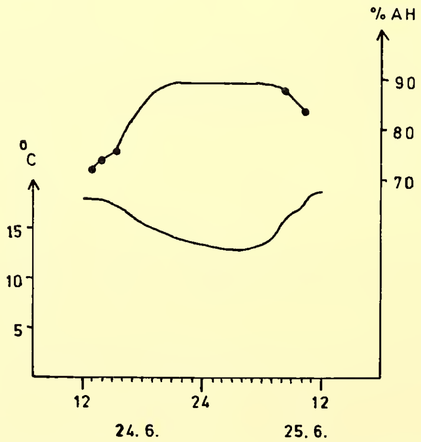


Diagram 11: Temperature (lower line) and airhumidity (upper line) underneath a rose-bush in Old Marpha, 3000 m.

Besides the investigations on microclimate at points of comparable equality (rocks) in the different working camps we have undertaken several checks of air-humidity and temperature at other selected places. An important role in the habitat of groundliving animals has to be attributed to the vegetation, especially bushes, as places of rest, hiding, watching and others. A comparision of temperature underneath a dense bush with temperature of solar irradiation (diagram 10) shows the equalizing effect of the branches' shadow. Temperature of solar irradiation is much higher in the middle of the day and considerably cooler during night, until it rises rapidly again in the morning after sunrise. The measurement underneath a dense rose-bush in Old Marpha (diagram 11) at an altitude of 3000 m covered only the time of a single day. Nevertheless it shows remarkably high values of air-humidity and temperature, even during noontime and night respectively, as a consequence of the wet and warm conditions brought in by the starting monsoon. Although the branches of bushes cause an equalizing effect on temperature and air-humidity in the rather wet period of premonsoon and monsoon times this effect is less distinct if one enters a real dry and, moreover, high mountainous region. In the Syang Khola valley at an altitude of nearly 4000 m the situation was intensified by addition of dryness of the northern Kali Gandaki area plus solar irradiation at high altitude. Therefore the lines of temperature and air-humidity gained under a bush of *Juniperus* (diagram 12) follow nearly exactly those of the main conditions. It has, however, to be taken into consideration that the values of main air-humidity and of main temperature have been taken in the shadow of an open stonehut, whereas the bush of *Juniperus* was standing in the sunshine fully exposed to the solar irradiation of that high altitude. Special interest has to be paid to the line of air-humidity. It shows a strong fluctuation of values between day and night, but compared with the observations of Jomosom in diagram 9, the lowest values still remain above 70 %, certainly a result of the wetter and cloudier conditions on the high slopes of this area during the monsoon time in contrast to the dry, windy bottom of the Kali Gandaki valley.

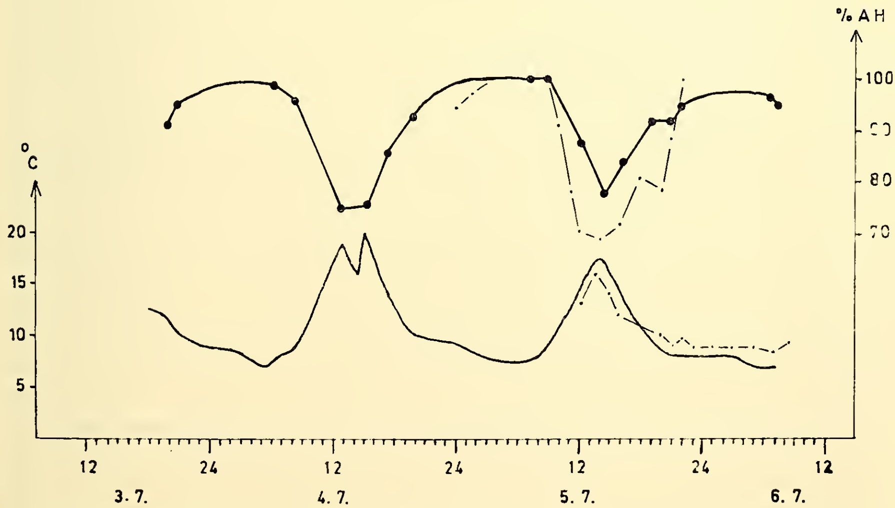


Diagram 12: Temperature (unbroken lower line) and air-humidity (unbroken upper line) underneath a bush of Juniperus in the Syang Kola valley, 3970 m. Broken lines indicate additionally the main temperature and the main air-humidity of the camp's locality.

When we have found a strongly varying air-humidity and temperature even underneath bushy vegetation in the upper Syang valley, the conditions underneath rocks on high altitude places give a quite different picture. In diagram 13 the measurements were carried out on the eastern slopes of Dhaulagiri at an altitude of 4150 m, in diagram 14 at an altitude of 4210 m in the upper Syang valley. All lines represent themselves strongly balanced. The air-humidity remains constant around

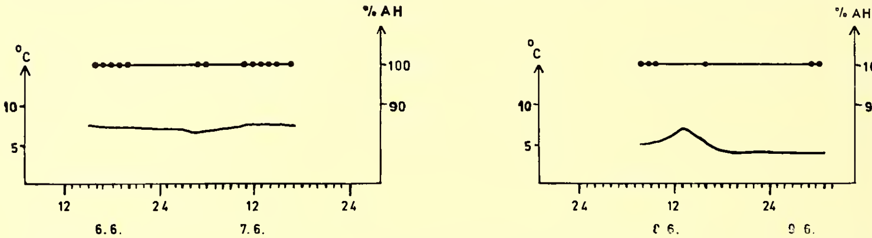


Diagram 13: Temperature (lower line) and air-humidity (upper line) at a high altitude pasture on the eastern slopes of Dhaulagiri.
left: deeply underneath a rock, 3700 m; right: underneath rocks in a burrow of *Ochotona roylei*, 4150 m.

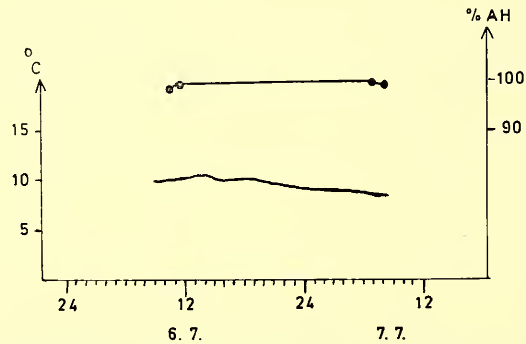


Diagram 14: Temperature (lower line) and airhumidity (upper line) deeply underneath rocks in a burrow system of *Alticola stoliczkanus* located in the Syang Kola valley, 4210 m.

100 %, the temperature shows a small peak at 3° C difference only in the burrow of *Ochotona roylei* at diagram 13 b. This is certainly due to a short period of sunshine at the early afternoon of this day. The average 3—4° C difference of temperature between the conditions at Dhaulagiri and those in the Syang valley are caused by the forthcoming monsoon. From the beginning of June up to the beginning of July the climate was becoming gradually warmer. Temperature measurements in the burrow system of small mammals in the European Alps have been carried out by HALBGEWACHS (1962) on the alpine *Microtus nivalis*. His results, being taken in the months September-December, show the same balanced temperature during night and day in the mices' burrows. Summarizing it can be quoted that small mammals, such as *Alticola stoliczkanus* or *Ochotona roylei*, in their burrow systems at high altitude, live within very constantly balanced climatic conditions under which the high level of air-humidity is of remarkable interest.

6. Results and discussion

6.1 General and insects

The meteorological data show clearly that the southern slopes of the Annapurna range belong to a very humid type of monsoon climate unique for Central Nepal, a type which normally can be found in East Nepal east of the Arun river and further on in the eastern Himalaya. Vegetation of this area gives the same indication. There is also evidence that at least in Lepidopterous fauna some eastern species have an isolated distribution in this area. In contrast the upper Kali Gandaki valley gets dry very soon and the type of climate changes to BSk sec Köppen, forming a second maximum of precipitation during winter and so forming a climate which comes near the one of West Himalaya, that means a mediterranean type. The reasons for this type of climate are the rainscreen effect of the mountain ranges of Annapurna and Dhaulagiri and the drying influence of the strong southerly wind originating by the diurnal irradiation on the Tibetan plains. The valley has but a small amount of cloudiness which makes possible a long lasting sunshine every day and increases the main temperature to two degrees more compared with the same level on the southern mountain side. In the valley between the gorge near Kabre and Kalopani-Dhumpu there is a transitional zone where the amount of rainfall rapidly decreases. The rainfall data are impressive (see fig. 2). This transition is evident by the vegetation and by the distribution of many species of animals. Except migrating species of Lepidoptera, the movement of which is supported by the strong wind, the number of oriental, humid-adapted species decreases very rapidly and north of the line Dhumpu-Larjung it comes near zero; while here the true Palaearctic elements dominate. Considering the general distribution of these species we may find them in the bordering areas towards the north in Tibet and further on towards the west in dry areas in West Nepal, in western Himalaya, in Kashmir and Karakorum. At least many of these elements are of east mediterranean origin. Towards the east the distribution ranges in Nepal just to the Manangbhot area and in the north along the Tsangpo valley. Considering the immigration of these species from the west it seems easy for flying animals to follow the suitable climate until they reach their pejus somewhere near a line below the 1000 mm-level of rainfall. As mentioned above, the transitional zone is between the gorge and the ridge behind Dhumpu. Here we find a mixture of Palaearctic and Oriental species, the composition of which has a shifting aspect depending on the season. While in the south there is a lot of premonsoonal precipitation due to convection movement, here there is rather little rainfall during this season and the percentage of Palaearctic species is rather high. Later with the incoming monsoon and increasing humidity the amount of Oriental species seen is much larger. The 1000 mm-line of rainfall is not solely the factor influencing the distribution of species. There is also the belt of clouds which from spring to autumn covers a certain level of the southern slopes and forms a barrier for heliophilous species. During the monsoon season these clouds also cover the alpine zone and give a reason for the very poor fauna of diurnal lepidoptera of this area. Even north of the main range, especially on the slopes above the dry valleys, there is some cloud cover. Climbing such a slope the fauna shifts, including many humid adapted species, higher up. To conclude from these facts, and to make an attempt to limit the Palaearctic region, we propose a line of about 500 mm precipitation connected with BSk-climate. The latter is highly important because, as shown before, the amount of sunshine and humidity by clouds plays an important role in ecological conditions influencing the distribution of species. So, finally, the top of the main range can be defined as the border between different types of climate, different types of vegetation and the border between Palaearctic and Oriental zoogeographic regions. Palaearctic species living south of this line have immigrated and adapted to the special climate of these localities. The definition of this border, therefore, is an ecological one.

It is noteworthy that the transitional zone in the Kali Gandaki valley from the gorge to the ridge north of Dhumpu is but 10 km, while the way from Gandrung to Jomosom 70 km approximately. Here, in this small area, many other problems of ecology could be studied.

6.2 Groundliving vertebrates

Concerning the life conditions of groundliving vertebrates, such as amphibians, reptiles and small mammals, the climatic and vegetational situation and all its transitions in the area under study between Annapurna and Dhaulagiri is of special interest too. The details of climate in connexion with details of vegetational zonation give support for the understanding of distribution patterns in the three groups mentioned, of patterns of breeding ecology in Salientia or of patterns of behavioral, diurnal activities of reptiles. In the region of temperate fog forest on the southern slopes of the Annapurna mountain range the fauna of amphibians, reptiles and small mammals in its structure is completely dependent on the extremely wet conditions of the monsoon climate. In this respect it does not differ much from the faunal structure further east on the southern slopes of the Himalaya between Manaslu and Khumbu mountain range and further on until Sikkim, Bhutan and northern Assam. Some details in distribution of small mammals, for instance *Rattus eha — R. fulvescens* in the inner Modi Khola or *Soriculus caudatus — S. leucops*, will be discussed in a later publication. But as a whole all these animals undergo the influence of the monsoon climate and its vegetational expression. As previously described in this paper in the chapter on detailed definitions of the several types of vegetation, the lower region of our research area mainly consists of cultivated land. This open landscape offers, in its non-cultivated parts, ideal life-conditions for reptiles, such as agamas (*Calotes* in the lower region up to 1500 m and *Agama* above this altitude), skinks *(Scincella)* and several snakes, or in its wetter localities with rivulets and ponds to amphibians like toads and frogs *(Bufo, Microhyla, Megophrys, Rana, Amolops).* Although this landscape is open to solar irradiation humidity-dependent animals find enough humid hiding-places if the open environs become too hot or too dry.

As soon as one enters the dense forests, for example the temperate fog forest in the Kyumnu Khola with its oak- and *Rhododendron*-trees, we reach a very effective altitudinal distribution barrier for amphibians as well as for reptiles. There is only one species of reptiles, *Japalura tricarinata*, which lives right inside the dense forest. At first sight it seems that many species of amphibians and reptiles (skinks, snakes, frogs, toads) enter the forest, but they always keep to more or less open places caused by human influence, such as footpaths, forest-pastures or localities strongly degraded by cattle grazing. It seems that the whole distribution patterns of amphibians and reptiles in the outer and inner Himalaya of Nepal above 1000-1500 m are very much dependent on the human changes carried out on the original vegetation. So most of the agamas are seen on the rocks and stonewalls along the footpaths; while skinks, snakes, toads and frogs are found in the region of cultivated land, of settlements and of forestpastures. However, what applies to amphibians and reptiles does not, as a whole, pass for small mammals. They are much less specialized with respect of dense forest and those forests do not even act as altitudinal dispersal barriers for them. On the contrary, it seems that just the forests offer especially acceptable life conditions for small mammals and it seems that the high level of airhumidity in their habitats is a welcome basis for their existence. Whereas amphibians and reptiles in our area of research end at the timberline and above, we find a rich life of small mammals in those localities.

Fig. 17: Still rather humid biotope of mice and mousehares *(Ochotana)* at Kalopani, Kali Gandaki valley. The instruments for measuring temperature and air-humidity were placed deeply underneath the rocks.

When we pass over to Kali Gandaki valley the conditions in the lower portion of the valley are continued as mentioned before. But above the gorge conditions of climate and vegetation begin to change and the influence of this change can be read off also from the vertebrate fauna. Still the slopes on the upper parts of the valley's slopes act as barriers for the altitudinal distribution of amphibians and reptiles, but the open landscape with meadows, fields and yak-pastures climbs the slopes east and west of the river-banks and allow the agamas, skinks and toads to reach altitudes up to 3000-3100 m. Again the correlation between the distributional patterns and the influence of man on the vegetational landscape is evident. Nevertheless the monsoon still penetrates into the southern part of the Thakhola-area up to the village of Larjung and the wet climatic conditions create a rich life of toads and frogs. During the months of May and June a vast number of spawning sites, of toads' and frogs' spawn and of tadpoles, can be found. On the other hand, less humidity as a whole is indicated by a decreasing diversity of herpetofauna in this region. Also, in the structure of the small mammals' fauna there is a gradual change above the gorge in the Kali Gandaki valley. Most of the species known from the southern slopes of Annapurna still occur. However, those which are most dependent on wet conditions, as for instance *Rattus eha* or *R. fulvescens,* have been left behind; whereas others like *Apodemus ghurka* predominate. The situations in respect of the structure of the small mammals' fauna at the timberline and above are the same on the southern Annapurna region as on the southeastern slopes of Dhaulagiri or the southwestern of the Nilgiri mountain range.

Fig. 18: Biotop of mousehares *(Ochotona)* in the Syang Kola valley at an altitude of 4500 m. Under the rock the exit of the mousehare's burrow system. The instruments for measuring microclimatical conditions were placed at this spot.

The farther north one enters the Kali Gandaki valley, the more change from humid and semihumid to dry, arid conditions are to be found. On the valley's bottom there are still enough humid possibilities for the existence of frogs and toads, although the number of species decreases. The same decline of number of species can be seen in the reptiles. Only forms which are able to stand a high dryness like the less specialized *Agama tuberculata* and *Scincella himalayana* or the snakes *Amphiesma sieboldii* and *Agkistrodon himalayanus* live in the region from Tukche up to Marpha and Syang. It is noteworthy that the skinks and the snakes seem to keep close to cultivated land. Above Syang and around Jomosom there remains only *Agama tuberculata* and it reaches, at 3400 m, the highest altitudes of its distribution in this area. The change is rather abrupt and takes place in a very short distance, according to the quick change in climate and vegetation. Even more abrupt and impressive is the change in the small mammals' fauna. Within a distance of only a few kilometers the last species from the humid area in the south disappear and forms from the western, mediterranean sphere, such as *Apodemus sylvaticus* on the bottom of the Kali Gandaki valley, or from Central Asia, such as *Alticola* or *Ochotona* in high altitudes reaching and extending the timberline, predominate. The area north of Jomosom is unknown so far, but it can be expected that the conditions known from around Jomosom will represent themselves even more expressively.

7. Summary

The area studied was Annapurna south slope and Kali Gandaki valley up to Jomosom. Data of vegetation and climate were collected and compiled. They show clearly that from the very wet south slopes to Jomosom there is a remarkable transition in climate, especially rainfall and temperature, which also influences the vegetation. This transition takes place within a very short distance. The differences in ecological conditions are expressed in the distribution of animals. One can find quite a clear limit of distribution in Palaearctic and Oriental species, each of which claim a special type of climate. The most typical limit is near Dhumpu, where the rainfall goes down below 1000 mm a year. Reasons for the quick change in climate are the rainscreen effect of the high mountains, the drying effect of a very strong southerly wind and the influence of east mediterranean cyclones during wintertime from the northwest.

Temperature and air-humidity were measured on the ground of the main biotopes in order to obtain information about the microclimatic conditions of the groundliving animals. Conditions under rocks in the Kyumnu Khola on the southern slopes of Annapurna represent themselves strongly balanced, with exceptionally high air-humidity. The same passes for the microclimatic conditions at Kalopani in the Kali Gandaki valley, with a difference of balance between premonsoon and the beginning of monsoon time. At Choklopani, Old Marpha and at Jomosom the measurements undergo a strong daily oscillation, according to the drier situation, but still the air-humidity remains at a high level. Measurements on a high altitude camp in the Syang Khola valley (3970 m) show the same effect as at the bottom of the Kali Gandaki valley in this region, with only lower level of temperatures. Additional measurements in the burrow systems of small mammals *(Ochotona, Alticola)* in altitudes between 3700 and 4200 m again yield a strong balance in temperature and air-humidity (around 100%).

The distribution of palaearctic Lepidoptera north of the limit of Dhumpu is made possible by immigration from the west and north-west, that is from the West Himalaya. For diurnal heliophilous Lepidoptera the distribution towards the south is limited by the high amount of cloudiness, which gives less sunshine than required for these animals. A similar effect is found on the southern slopes in the belt of fog, where the gene exchange is made impossible for races living below and above this level, for example *Papilio machaon.* Therefore subspecies, genetically determined, have developed in these areas.

Furthermore, the influence of ecological conditions on non-genetical variation has been studied. Certain species have strongly influenced coloration by temperature, much less by humidity. The borderline between Palaearctic and Oriental zoogeographic region is, based on ecologic data, discussed. It is, more or less, the ridge of the high mountains.

The effect of climatic as well as vegetational conditions and changes on the structure and situation of the ground living vertebrate fauna in the area under study is discussed. The situation on the southern slopes of Annapurna is similar to that in the whole eastern Himalayan region from Manaslu to the Khumbu mountain range, to Sikkim, Bhutan and northern Assam. The importance of human influence on the original vegetation (cultivated land, settlements, pastures) for the distribution patterns of amphibians and reptiles is evident. In the Kali Gandaki valley above the gorge climatic and vegetational conditions change and so does the structure of the ground living vertebrate fauna of amphibians, reptiles and small mammals. Whereas the penetrating monsoon in the southern Thakhola-area still creates a rich life of toads and frogs, with its explosive spawning ecology in spring and a variety of reptile species, there remain only a few species of frogs and only one of the agamas in the dry region around Jomosom (after a section of transition further south).

The structure of the small mammals' fauna completely changes in a very short distance in the upper Kali Gandaki valley, with predomination of the mediterranean *Apodemus sylvaticus* on the bottom of the valley and of the central-asiatic *Ochotona* and *Alticola* at higher altitudes.

8. Literature

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